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COLD: PHYSIOLOGY, PROTECTION AND SURVIVAL

ADVISORY GROUP FOR AEROSPACE RESEARCH AND  
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COLD: PHYSIOLOGY, PROTECTION AND SURVIVAL

by

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## PREFACE

This monograph is written at the request of the Editorial Committee, ASMP, AGARD. The subject *Cold Physiology, Protection and Survival* covers a very broad area. The single person must be considered poorly equipped, landing on Arctic ice or in the mountains under difficult meteorological conditions. We must also consider a group of people, more adequately equipped and functioning under less stressful conditions.

I was asked to write about the physiological responses of persons exposed to thermal stresses. This monograph was to include what I considered to be of importance both in organizing courses and rescue operations in cold land masses, to teachers, physicians, and equipment officers of NATO Forces. The content is based on many sources; my own knowledge and experience, discussions with others, and published materials.

It is a pleasure to especially thank Lt Col James H. Veghte, USAF, 6570th Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, who has read the manuscript, both at the earlier and later stages, and who has shared his experiences and given his assistance in the writing of this book. His help with translation to English and his editorial assistance is very much appreciated.

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## **SUMMARY**

Survival in the cold regions of the world involves a basic understanding of physiology, practical experience, and a thorough knowledge of survival equipment and use of natural materials. This paper summarizes knowledge in these areas as well as a lifetime of experience in northern regions of the world, primarily Norway, and knowledge gained on expeditions such as in the Himalayan mountains. It is a practical paper and if one assimilates its contents then survival in a cold environment is greatly enhanced.

**PART ONE**  
**INTRODUCTION**

The possibility of survival in a cold environment alone or in combination with other physical stresses, lies more in the field of technology and engineering, than in modifying human physiology. I have therefore tried to include some practical points concerning survival techniques and equipment. As equipment will often be a question of funds, possibility of transport, or weight, I have attempted to concentrate on the more serious problem encountered by a single man with simple equipment which has the highest possible efficiency/weight ratio.

It has not been possible to discuss in this text the various differing views, nor the relative importance of these views. Also, it has not been possible to avoid being personal, subjective, and categorical.

## PART TWO

### BODY TEMPERATURE AND ITS REGULATION

#### GENERAL

Under normal conditions, the central body temperature is regulated near 37°C with only diurnal variations. With exercise, the regulatory mechanisms do not keep pace with the heat production and the central body temperature will rise. Similarly, during hypothermia, the body temperature will fall. In this book we are mainly interested in hypothermia.

While the temperature of the central nervous system and the thoracic, abdominal and pelvic viscera (the core) is regulated near 37°C, the temperature of the peripheral parts (the shell) may fluctuate considerably, depending upon the production of heat by the body, and upon the heat loss. The regulation of temperature is a very complex, but well coordinated reflex action in which many body functions are involved. We must consider both the afferent impulses, the lower and higher coordinating centers in the brain, and the effector mechanisms.

The principal afferent receptors are the sensory endings of the nerves in the skin, although some nerves have been identified which respond to heat in organs and some thermoreceptors have been located in the spinal cord. The primary coordination centers are located in the hypothalamus in the mid-brain. There are both heat loss and heat conservation centers which are mutually inhibitory. The system is very sensitive to temperature changes and respond as well to afferent neural impulses. The thermoregulatory function is depressed by reduced oxygen tension, by drugs, and shock conditions. The effector mechanisms involve most tissues and organs, such as the skin, muscles, blood vessels, liver, thyroid, and adrenals. Local reflexes (axon and spinal) play a role in temperature regulation when many secondary reactions are put into action (nervous, humoral).

#### HEAT PRODUCTION

The heat produced in each cell is derived from combustion of food stuffs. The carbon combines with oxygen obtained from the inspired air. Carbon dioxide is formed and is eliminated by the airways. The heat production can be calculated if the amount of oxygen consumed or if the production of carbon dioxide is known. The heat produced is derived from several sources: basal combustion of chemical energy, work, muscle tension, shivering, and extra thermogenesis.

*Basal combustion.* The basal metabolic rate (BMR) is defined as the metabolism of a fasting person, lying at rest, in a comfortable temperature, without extraneous sensory inputs such as noise or visual stimuli. Metabolism is usually expressed as oxygen consumption or calories. The total BMR varies with the mass. For interindividual comparison, it is best to relate metabolism with body surface area ( $m^2$ ), time (hr), and weight (kgm). In a medium sized man (175 cm height,  $1.85 m^2$ ) the BMR varies from 35 to 40 kcal/ $m^2$  hr or approximately 225 ml  $O_2$  is consumed per min. (ex.  $40 \times 1.85 \cdot 24 = 1776$  kcal/day). With sleep the metabolism is somewhat lower and the term "basal" should perhaps be replaced with "resting" (RMR) in non-sleeping persons. RMR is lower in women and is reduced with increased age. The RMR is not affected by changes in barometric pressure but slight differences may be seen in different races or climates.

TABLE 1

#### Some Metabolic values for nutrients

	Carbohydrates	Fat	Protein
Kcal/g	4.1	9.3	4.3
Liter $O_2$ /g	0.75	2.03	0.97
Kcal/l $O_2$	5	4.7	4.5

**Heat production during work or exercise.** At rest, the muscles produce approximately 10% of the total heat production of the body. During work or exercise the body's heat production may increase 15–20 times the resting value, up to 1400 kcal/m<sup>2</sup>hr and O<sub>2</sub> consumption may increase from 200 to 6000 ml/minute. The mechanical efficiency of the muscles is normally 20 – 25%, or less than that of many modern machines. The other 75 or 80% of the combustion energy is heat. Light work (600 kpm/min) is equivalent to 60 kcal/min. Theoretically light work would increase the body temperature of a 70 kg. man 1°C in 10 minutes (70,0,82.1 is almost 60 kcal, 0.82 is the approximate value for the specific heat of the body).

**Muscle tension and shivering.** Local cooling of the muscles at rest will increase the tension, but reduce the metabolism. Shivering and increased tension is mediated by the temperature regulating centers that are activated by a cold stimulus. During sleep there may be increased muscle tension and some shivering, which of course is of great importance in maintaining normal body temperature. Shivering is not continuous. It characteristically waxes and wanes in intensity. It varies with respiration and exhibits a long biorhythm. Metabolism and heat production may be increased 5 times above the BMR with shivering. All striated muscles as well as the diaphragm participate, and the whole body may shake violently.

Voluntary contraction has been thought to be less efficient in heat production than shivering. However, as long as no external work is done, a given oxygen consumption level, whether due to shivering or to voluntary activity, will produce the same heat. Voluntary contraction will reduce shivering.

**Extrathermogenesis.** This source of heat production is based on animal experimentation and is a controversial subject if extrapolated to humans. As previously described, temperature regulation is very complex and many organs and functions are involved. Extrathermogenesis appears to be localized in muscles. Interestingly, it occurs without increased tonicity, shivering or electrical phenomena. It is not possible to record it electromyographically. Increased non-shivering thermogenesis would be ideal during cold nights and would enhance sleeping. It has, however, not been exploited sufficiently and has not been used in selection of personnel for assignments in cold regions. In animals "non shivering thermogenesis" occurs in the liver, diaphragm and heart. Brown fat is of importance in some animals, but is not present in adult humans.

All muscle compensatory metabolism is reduced: 1) by lack of oxygen, 2) in hypercapnia associated with closed rooms or tents, 3) by use of sleeping drugs, antipyretics, insulin, and 4) by a poor nutritional or physical state. Hypothermia slows down all chemical reactions and accordingly all metabolic processes.

**Solar Insolation.** For the sake of completeness, it should be mentioned that the body can absorb energy such as heat by solar radiation or other outside sources and by convection/conduction from the microenvironment. This additional energy may amount to as much as 200 kcal/m<sup>2</sup>hr.

## HEAT LOSS

The heat produced in the body is stored for very short periods and must be balanced by corresponding heat loss. The transfer of heat within the body from the place of production to the skin is accomplished by conduction – convection. Conduction refers to the molecular transfer of energy from a higher thermal or energy state to a lower energy level.

Thermal conductivity varies in different tissues. Fatty tissue has a low thermal conductance and heavier people have an insulative advantage during cold exposure. It should, however, be stressed that slender people often have better circulatory adjustments of skin vessels. They sweat less and have a higher lean body mass per kg body weight. A compromise between the meager and the fat type would be ideal for cold tolerance and in the event of disease or hunger.

The convective transport of heat within the body is achieved by the blood. Warm blood from the site of production is circulated to the skin. Most of the transport of heat within the body is accomplished in this manner. Although, considerable convective heat exchange occurs in the lungs.

**Vascular countercurrent.** Under cold conditions the skin vessels constrict, and the shell temperature is lowered. Thus the conductive and convective transfer to the skin is reduced, and body heat is conserved. This is also achieved by the counter-current exchange principle in the vascular vessels of the extremities. The artery (small cross section and high blood velocity) and the vein (big cross section and very low blood velocity) lie close together with the venous anastomoses partially surrounding the artery. Therefore, the arterial blood from the heart with a temperature of 37° transfers heat to the cooler returning venous supply with the result that the arterial blood reaching the extremities may be 10–15 degrees lower. This thermal exchange results in energy conservation. Under conditions of high heat production there will be a redistribution of blood to various regions of the body. The venous blood will be shunted and pass into the superficial veins towards the heart while the warm arterial blood will pass directly to the periphery and cooled. The shell and extremity temperatures will be elevated and serve as temperature buffers. If the shell temperature is elevated, it serves as a heat reservoir when the individual is exposed to cold and may provide 100 kcal. The converse is also true, the shell can serve as a cold reservoir when coming from a cold environment into a warm room.

In summary, most of the heat loss from the body to a colder microenvironment is by means of the exchange of energy at the periphery with smaller respiratory, urine, and fecal thermal losses.

**Body Heat Loss. Skin Temperature.** The average skin temperature depends upon the total body heat content and varies in different regions of the body. In comfortable environments, these temperatures are: head 34°, trunk 35°, thigh 33°, calves 31°, feet 30°, forearm 31°, and hands 30°C. Therefore, the average skin temperature under comfortable, resting conditions may vary from 28° to 33°C.

All warm-blooded, homeothermic animals have a characteristic lower critical temperature at which chemical thermogenesis occurs. For a nude person, this "*critical temperature*" is about 28°C. It may vary between ethnic groups. If the surrounding temperature is lower than 28°C, skin temperatures fall and the thermoregulating mechanisms respond by constricting the peripheral blood vessels, shivering, and increasing the metabolism. The metabolic increase is proportional to the lowered skin temperatures. In addition to skin temperature, the subjective feeling of cold will depend upon, 1) how rapid the onset of cooling occurs, 2) the thermal gradient from deeper to superficial tissues, and 3) the total body heat content. Sudden cooling with a high thermal flux and low body heat content (heat debt) will result in the strongest, subjective cold feeling. During exercise, the skin temperature is reduced without any subjective discomfort or reaction. Although skin temperatures can vary widely between the different parts of the body, these differences must not exceed certain values. If a certain body region or area is cooled sufficiently, high central body temperature, vasoconstriction, and goose flesh will occur.

The temperature on the neck and face is always relatively high (Fig.1(a)). There is little or no vasoconstriction of the head vasculature and the skin blood flow may even be increased at lower temperatures. The heat loss from these areas may therefore be very high. At -4°, at rest and with proper clothing, the loss may represent half of the total heat production<sup>1</sup>. These areas may therefore serve as a good outlet for heat under high production, but they must be well covered with low activity.

The circulation in the fingers can vary enormously, from 1 to 150 ml/100ml tissue per minute and considerable heat may be lost from this region even under warm environmental conditions. In cold, the heat loss from the fingers will be very low because of intense vasoconstriction and resulting lower skin temperature.

Heat from the body is transferred from the skin to the surroundings by 1) conduction and convection, 2) evaporation, and 3) radiation.

**Conduction and Convection.** The microenvironment, air in close contact with the skin, is directly warmed by conduction. The warmer air can be dissipated by wind, body movements, and convective pumping under clothing. Since thermal conductivity of the air is very small, still air is a good insulator and is the basis for insulation in clothing and building materials.

Theoretically, there cannot be any convective loss from the body without air movement over this surface. Physicists prefer the term "heat transfer" or "flux" which includes both conduction and convection. Heat transfer is usually expressed in kcal/m<sup>2</sup> hour. On a curved surface the total heat transfer is greater than for a flat surface. Therefore, adding a layer of insulation on a cylinder of small diameter (a finger) would increase the heat loss. This paradoxical effect exists until a thickness of 6 mm is added.

Conduction losses would be greater in water.

Under ordinary conditions with a moderate work load almost all heat is transferred by conduction/convection. The amount lost, will increase with higher skin temperatures or a lower ambient temperature. But under hard work the evaporative loss will contribute to an increasing percentage of the total heat lost and will be larger than the convective loss. It is important to ventilate clothing at the onset of exercise to achieve the best possible cooling by conduction/convection only, and to avoid sweating.

**Evaporation.** Evaporation from the skin and respiratory tract will normally represent 20% of total heat loss. The evaporation of sweat is the body's main defense against heat stress when the loss by conduction/convection does not keep pace with heat production. Sweating may start very early in exercise, probably the immediate action of adrenaline, and before the temperature of the skin and the peripheral parts is increased. One is not always aware of this onset of sweating. The relative humidity under the clothing will increase rapidly. The water vapor will pass out to the outer layer of the clothing and condense and freeze there if it is cold. With continual exercise, the temperatures at the periphery of the body will be increased and considerable condensation accumulates in the clothing, especially the socks. It is very important to open up the clothing before or at the start of exercise, not only to achieve good cooling by conduction/convection, but also to allow evaporation to occur. To feel cool at the start of exercise presents no risk for a trained man, even in a very cold environment. Although this is a known fact, in actual practice it is not done. If the sweat does not evaporate, if it is dried off or drips off, or if it is wicked into the clothing, the heat is not removed from the body.

The amount of water lost during exercise may be considerable in a cold environment, perhaps 1000 - 2000 ml per day. Since the evaporative heat is 580 cal/ml, 580 kcal will be needed to evaporate 1000 ml water. If most of

the sweat stays in the clothing, it will represent a very serious heat loss if it evaporates during the night.

Sweating is usually not increased after fluid intake. If there is no hypohydration, ingested water will quickly be excreted through the kidneys. Some salt loss will occur with sweating, but under normal conditions it rarely is of importance. Unaclimatized persons will sweat more than acclimatized individuals who have a more effective conductive/convective heat loss. The uninitiated person is often more afraid of the cold and will not consider the importance of keeping the clothing dry. Dry clothing is a better insulator than wet clothing.

Some water from the body will pass out through the skin by simple diffusion. It is this insensible water passage which keeps the skin soft, never completely dry. Under calm conditions the diffusion may amount to 300 - 500 ml per day and it is always at least 10 ml/h. When the skin temperature is raised, there is only a negligible increase. Usually this insensible perspiration is not recognized because the vapor will pass out into the clothing or through the pores. On the feet the passage of insensible perspiration will be inhibited by boots and the vapor will condense. The socks will therefore get damp, even if the external environment is dry and cold. This fact dictates the use of lower boots with better convective exchange. The insensible passage may be reduced by "sweat-reducing" solutions applied locally. These solutions can not be recommended for periods longer than one day as susceptible persons will get sore skin and infections.

The content of water in the clothing is difficult to judge, but usually is more than one would expect. In cold, quiet weather, practically all the moisture stays in the clothing and it requires hours to dry in the wind or with modest body activity. Psychically released sweat on the forehead, palms and soles of the feet, caused by stressful conditions such as fear, tension, stomach upsets, or shock does not effectively regulate body temperature. As the skin temperature usually is low, when emotional sweating occurs, most of it is absorbed in the clothing and will increase the risk for cooling under difficult conditions.

A considerable amount of heat and water may be lost through expired air. In our nasal air passages we have a counter current exchange which conserves some heat and moisture. At inspiration the mucous membranes will be cooled and dried, while the next expiration will rewarm these tissues and a part of the moisture from the lungs will condense on the cooler mucous membrane. This thermal exchange is most effective with nasal respiration, where the contact between air and mucous membranes is much greater than with oral respiration. With either a narrow nose passage or with exercise, a higher breathing rate or volume will result in oral respiration. In dry, cold air, cooling occurs along the upper regions of the trachea. Also, a rapid change from cold/dry to warm/moist condition insults the epithelial lining. Dryness appears to reduce the acitivity of the cilia lining the respiratory tract. When coming from the cold into a warm, dry room, often filled with smoke or dust, swelling of the nasal membranes may result and perhaps block these passageways. Often discomfort occurs immediately upon entering such a room because of vascular dilation and rapid swelling. This response appears to diminish with cold acclimation.

**Radiation.** A certain percentage of incoming radiation is reflected while the rest is absorbed and its energy is given off at the surface as mentioned previously. It is the visible infrared rays with wave lengths longer than 740 nm, which are of interest quantitatively for energy exchange. The higher the temperature of the object (bare skin or clothing) and the lower the surrounding temperature, the more heat is lost by radiation. This loss can be great under a clear sky, much greater than many people are aware of.

It should be noted that the emitted visible radiation is of less importance, thermally, compared to the infrared.

## PART THREE

### ADAPTATION, ACCIMATIZATION

#### GENERAL

To avoid ambiguity, the following definitions are utilized in this text:

*Adaptation* - genetic changes occurring during a period of several generations.

*Acclimation* - functional compensation over a period of days or weeks in response to a single environmental factor.

*Accimatization* - functional compensation over a period of days or weeks in response to a complex of environmental factors.

*Habituation* - what one is accustomed to.

Man, for all practical purposes, has very little opportunity for real physiological adaptation. However, subjectively, we are better able to tolerate cold stress after a few days of adjustment. In cold environments, man depends mainly on clothing and other technological conditions in order to survive. Of course some primitive people live under inconceivably cold conditions.

Darwin's dramatic description of the Tel del Fuejo Indians and their ability to withstand wet cold, or to walk in snow and sleet almost without protection is one example. Also, the Australian aborigines sleep nearly nude in temperatures near 0°C. They incur considerable loss of body heat which results in low skin temperatures. Yet they sleep quite well without muscle shivering. As sound sleep is so important, it can be taken as an indication for useful adaptation. Considerable physiologic studies have been conducted determining if metabolism is increased, or if the insulation is better (thicker fat layer, better vasoconstriction, better countercurrent) when the subject is cold stressed. With age, basal metabolism decreases as does the ability to tolerate cold. Small individuals with thin, larger body surface area/weight ratio, loose more heat per kg than larger individuals. Women have lower metabolism than males but have better insulation than men.

In some experiments, Eskimos and some Indians increased their metabolism during sleep (20 - 25%), but Laplanders remained close to basal levels under similar conditions. Similarly, some students exhibited a metabolism rate increase of 20 - 25% after six weeks of cold exposure associated with considerable physical activity. They slept better and shivering was reduced by the end of this exposure period. It has, however, also been shown that physical training, per se, without cold exposure gives the same metabolic compensation under subsequent cold stress. Most investigations of Arctic people do show a slight increase in basal metabolism.

*Human Experiments.* Experiments among western people have shown that the feeling of discomfort and pain is reduced after some days exposure. On holiday tours, for example, one may often suffer from the cold for the first few days, but later one can sleep better and enjoy oneself much more. The best explanation for this subjective feeling is that the peripheral or central nerve system in some unknown way have been habituated to the lower temperature. Another example of habituation is the Eskimo who can tolerate ice water on his hands but not on other parts of his body.

Other interesting examples of human tolerance to cold are seen in the Amas, Korean sponge divers. These women have a small increase in metabolism during prolonged cold water immersion. They do have better insulation and a low threshold for shivering. A more effective cardiovascular countercurrent could explain the reduced heat loss in these women<sup>2</sup>. Channel swimmers usually have a substantial fatty insulation. Neither with man nor animals has any increase in subcutaneous fat layer been seen after cold exposure.

Aquatic, homeothermic animals, have an effective cardiovascular countercurrent system and are also protected by a thick subcutaneous fat layer. After cold water exposures, some animals have a change in their intermediary metabolism. The suprarenal cortex and thyroid increase the production of active hormones. The respiratory quotient indicated an increased proportion of fat combustion.

*Local Adaptation.* Hand function is very critical. A local cold stress will rapidly lead to vasoconstriction and a lower hand skin temperature, reduced sensation, numbness, pain, and reduced muscle strength. It is a common impression

that outdoor workers have warmer hands than indoor workers. It may, however, be questioned if the conditions for testing the two groups have been comparable. Perhaps the warmer hands are due to increased activity more than to acclimatization. Others feel outdoor workers adjust or habituate to cold, but this has not been shown experimentally. Cold induced vasodilatation (CIVD) seems to occur earlier in people accustomed to cold.

Lower temperature for melting/stiffening of subcutaneous fat may be taken as an example of local adaption of tissue. If this were not so, the seal would be enclosed in a stiff fat layer. There is also some difference between summer and winter fat. The herring gull and other birds stand in ice water without muscular dysfunction and seems to have adaptation of nerve tissue<sup>3</sup>. But on the whole, there is little indication for local adaptation of any practical importance in man.

*Conclusion.* 1) No acclimatization is obtained without considerable exposure. 2) Man has very little physiological adaption to cold either general or local. 3) Habituation may be of value in adjusting to cold environments. 4) Practical attempts such as physical training, cold baths or rubbing the skin to increase circulation are questionable procedures to enhance cold tolerance.

## PART FOUR

### COLD INJURY

Cold injury may be local, general, or a combination of both. This type of trauma can be caused rapidly by an intense cold stress or by moderate cold over a long period of time.

**Pathology.** In rapid freezing the damage will be limited to the extracellular space. Crystals of pure water will precipitate and the concentration of electrolytes, proteins, enzymes will increase in the remaining tissue fluid. Intracellular water will be withdrawn. If the cooling does not go further, the process will stop at this point with the high concentration of intracellular constituents. The entire cell will freeze as a cryohydrate at a certain temperature. The cell membrane appears to act as a barrier between the two compartments. Intracellular crystals are considered not to be compatible with cell survival. Rapid freezing will result in small crystals in accordance with ordinary physical laws. Slow freezing results in larger crystals that may penetrate the cellular walls and extend from the extracellular into the intracellular space.

Red blood cells are very resistant to damage. They can be thawed after being frozen at very low temperatures and still regain full function. If freezing does occur, there appears to be a sudden break-down in the cell membrane. Sodium goes in and potassium and enzymes leave the cell. Some cells can reach this stage of electrolyte shift without being permanently destroyed.

In the past, the primary damage to the cell was thought to result from mechanical damage caused by the ice crystals and/or from slower chemical shifts. But changes in the concentration of salts, proteins and enzymes may be more critical. The different molecules and cell structures approach each other and new molecules may be formed. Also proteins, which are normally unfolded, contract and may become hydrated. Membrane permeabilities can also be altered and enzyme activity varies with temperature.

At times there is a striking variability in the extent of tissue loss and it has been suggested that the direct and immediate effects of cold may be overshadowed by some endogenously mediated factors. With cold, the oxyhemoglobin dissociation curve is shifted to the left and the unloading of oxygen is reduced. Therefore, quantitative and qualitative changes may occur in the metabolism. These changes are smaller in rapid deep freezing. Parallel with, or before the above mentioned changes, arteries constrict, probably due to a local reflex or direct action on the vessels (Fig. 1(b)). The arteriospasm may be a dominant factor in initiating and maintaining the circulatory impairment, but it is the venular dilatation and leakage which correlates best with the resulting tissue damage. Later at a lower body temperature, the constriction is centrally mediated by the hypothalamus, so that local warming may not cause vasodilation. Even if no ice crystals are formed in the tissues, capillary insufficiency will develop with dilation, stasis, and edema.

Injection of cortisone subcutaneously at this early stage will improve the prognosis considerably. Later blood platelets and other cell elements will accumulate. These elements can be disorganized, dissolved, sludged, and the structure lost. The process is reversible up to a certain point.

There is general agreement that the circulation is the principal factor in determining if the tissue will survive or not after rewarming. Tissues do not show the same degree of susceptibility. Blood vessels (endothelium) are highly susceptible - nerves and striated muscles are sensitive, connective tissue quite resistant, red blood cells, bone and tendons most resistant. The damage will depend more upon duration of cold exposure than on the absolute temperature. Rapid cooling and rapid thawing results in the least damage. Refreezing after thawing will increase the risk of tissue damage. The final tissue damage may be more severe at a temperature near 0°C than at colder temperatures.

It is common practice to classify frostbite clinically in three or four degrees. This does not serve any purpose. It is not possible at an early stage to decide the extent of tissue damage.

**Wind Chill.** Convective cooling by the wind is so important in cold exposure that it must be discussed. For example, an air temperature of +3°C and wind speed of 10m/sec will be equivalent to an exposure to an air temperature of -25°C with no wind. In still air, one can tolerate very low temperature, but even with very small relative air movement the cooling will be greatly increased (Fig. 1(c)). The "heat transfer coefficient" with a laminar flow over a smooth surface is approximately proportional with square root of wind speed. Different formulas have been derived. Siple and Passel's equation is :

$$H : (\sqrt{T_{0.9}V + 10.45} - V)(33 - T_A)$$

H is heat loss in kcal/m<sup>2</sup>h

V is wind speed in m/s

T<sub>A</sub> is air temp in °C. (4)

But, a word of caution - remember these curves and formulas are only valid for naked skin. Moisture is not considered in the calculation, even if the moisture content at temperatures lower than 0°C is very low. Subjectively, moisture content increases the subjective feeling of cold. Clothing will completely modify these calculations and the cooling rate depends on the curvature of the area, and the exercise level. Therefore in discussing wind chill it must be expressed in kcal/m<sup>2</sup>hr. Skin will begin to freeze at a wind chill value of about 1400 kcal/m<sup>2</sup>hr.

*Cold Injury.* The terms "chilblains", or "perniones" have been used to describe the superficial skin reaction after a moderate cold exposure which is intermittent over a long period. This condition is characterized by tender, red, pruritic macules which resemble erythema induratum. The same picture is also seen in cold allergic.

A moderate exposure will usually result in a localized red color (capillary dilatation) and warm skin. A moderate cold exposure results in a pale skin with a subjective feeling of cold, some pain, and numbness. After such an exposure the skin may remain red and perhaps some itching will persist for a few days.

In a more severe cold exposure, frostbite may occur. This is defined as freezing of the skin and is often preceded by a sting. Suddenly the typically white spot occurs with sharp delineation from the surrounding tissue. The patch is without sensation and there is no pain associated with this frozen tissue. The most typical locations for frostbite are the face and ears. These areas are easy to thaw. After thawing, some pain normally occurs. The only residual effect will be some redness as seen in Arctic people after repeated frostbites, and the skin often peels off.

If frostbite is not treated, further damage may ensue. On the extremities the peripheral blood vessels constrict, and the temperature may drop considerably with an increased sensation of cold. The sensitivity of the skin will decrease, both for tactile, and temperature senses, with the pain remaining after the onset of numbness. In some individuals peripheral circulation may increase, or a cold induced vasodilation response occurs and the pain may disappear. This oscillation between vasoconstriction and dilatation may occur repeatedly or until the skin temperature goes down further and all pain and sensitivity is lost. The dilatation-constriction-dilatation or "hunting" response reduces the risk for cold injury, but more heat is lost. This hunting phenomenon disappears after the core temperature falls below a critical threshold.

Finger dexterity which is so important for many vital functions in the cold, depends both on tactile discrimination and on muscle and nerve functions. Manual dexterity is severely reduced long before sensitivity in the fingers is lost. It may be very important to maintain dexterity in at least one hand by supplying additional insulation for one hand. Occupational exposure to vibration and cold, often combined with continuous tonic contraction of muscles have induced Raynaud phenomenon - "the white finger syndrome". In a future war with many machines and vehicles this trouble must be expected. Personal susceptibility and tolerance must be considered. The typical syndrome consists of transient episodes of digital pallor, with or without numbness and/or paresthesia, followed by cyanosis and erythema. The symptoms are precipitated by cold. Mild symptoms are very common in the population and increase with age. The symptoms may progress after the exposure has been discontinued and recovery is rare. A provocation test (submersion in cold water) has been suggested.

*Cold diuresis.* There is increased secretion of urine after local or general cold exposure. This diuresis may be a mechanism for removing some of the blood volume when it becomes excessive, as a result of vasoconstriction of blood vessels. The resulting relative hypohydration may persist for several days with loss of electrolytes, particularly sodium and chloride. This fact must be remembered when the individual is warmed as it may be a factor for late shock.

*Wet Cold.* Physiologic changes associated with a wet, cold environment occur more slowly than when exposed to dry intense cold. Both clinically and pathologically, however, there is considerable similarity. Wet cold injury may occur after exposure in cold air, but more often occurs after prolonged water immersion such as experienced after shipwrecks in which the victims have their feet in cold water for days. In World War I the same phenomenon occurred in the water filled trenches. Wet cold injuries are often called "trench foot" or "immersion foot". The circulatory impairment associated with this type of injury is pronounced. It does not appear serious the first few days, but the final result is often worse than expected. The converse is usually the case with rapid, deep, tissue freezing.

*Hypothermia.* When the physical and chemical regulation of body temperature does not keep pace with body cooling, the core temperature will fall. When a core temperature of 35°C is reached, the metabolism will be further reduced. At 33° consciousness may be lost, below 32° shivering stops, while at temperatures below 30° there is no longer any regulation and the body temperature sinks passively. Knowing that the chemical reactions are highly temperature dependent, it seems curious that it has been possible to resuscitate people who have had long respiratory and circulatory impairments because of hypothermia. Fall in blood pressure and heart arrhythmias are common at these lower core temperatures. A slight fall in central body temperature may occur without shivering or without subjectively feeling cold. However, usually there will be a stage of violent shivering and later an overwhelming feeling of

sleepiness and fatigue, symptoms which must be overcome. Impaired cerebration with misjudgments, and lack of mental coordination are common if precautionary rules are not followed. With further body cooling, there may be complete and prolonged amnesia, sometimes without lasting ill effects. Not only is a very low body temperature tolerable, but successful resuscitation and survival has been reported after prolonged hypothermia. There are reports of cases where a person has been buried for 2 days in snow after an avalanche<sup>5</sup>. Also resuscitation has been reported in a woman who had a rectal temperature of only 9°C. One is inclined to believe that some adaptive mechanisms are present.

Sometimes there is a sudden breakdown of the temperature regulation in cold environments, irregularities of heart rhythm and death, especially after weakening factors such as fatigue, poor physical condition, poor nutritive circumstances, dehydration, and drinking alcohol.

Two such examples are: 1) Three mountain climbers - one well-trained, the other two with little experience, encountered stormy conditions during descent. All felt cold and shivered violently. The experienced climber had to help the two weaker ones. Finally, one of the weaker persons sat down for a few minutes and suddenly died. The two remaining climbers progressed slowly downwards. Half an hour from a hut the remaining inexperienced climber sat down to have a rest. The trained climber gave this person all the clothing which was practical -- sufficient for very good protection, and proceeded to seek aid. But when the rescue team reached him 1 1/2 hour later, he was also dead. Resuscitation was unsuccessful. 2) Two men and one woman, 30 to 40 years old, were on a long cross country tour skiing. The ambient temperature was approximately 0°C and they were travelling into the wind. They felt cold, but all made good progress. At a short distance from a hut one of the men began to go more slowly and fell behind the others. When he didn't reach the hut, the others retraced their route and found him dead. From autopsies of cadavers of individuals such as the above who died in hypothermia, multiple ulcers in the stomach and blueish spots on the knees, elbows are often found -- perhaps related to liberation of histamine, serotonin, and enzymes.

*Treatment of local cold injury.* Life threatening hypothermia must take first priority in treatment. Tight fitting garments, straps, must be removed, boots cut open and taken off, and rings immediately removed. Rapid swelling may occur after thawing with great risk for total strangulation. If the central body temperature is reduced, it must first be brought up to normal. If the frozen area is too cold, the amount of blood which comes from the center will not be sufficient. Increased metabolism after rewarming will require increased blood circulation, which is one factor against rapid rewarming. Under certain circumstances, light body hypothermia might be of advantage.

The frozen cold part should be thawed and rewarmed as quickly as possible. Cold water, rubbing with snow, or massage is wrong. Warming can be achieved in many ways, but laboratory experiments have shown that the best results will be obtained with warm water with temperature 40 - 41°C. Higher bath temperatures up to 44°C may be used, but only for extensive frostbite damage and under well controlled conditions. The water must be stirred. Some vibration (whirlpool) is thought to improve circulation. Warm water has to be added as the bath temperature drops. A soap additive is recommended. If a warm bath is not possible, warm compresses (42°C water) which are changed frequently may be the next alternative. Rapid rewarming in water seems to give the best final result even if the treatment is delayed. Because a thermometer is rarely at hand, first aid crews should have training in judging water temperature. The reason for the beneficial effect of rapid rewarming is not understood. It appears paradoxical as metabolism is also increased.

The following points should be mentioned. Capillary leakage will be smaller. Big ice crystals are avoided. Also, if the period in which the enzymatic processes are changed is short, then the damage to the blood and vessels will be smaller. During rewarming, the patient should try to actively move the frozen area. If the part has already been thawed, slower warming therapy should be used. Radiative heat from an oven, open fire should not be used as the heating will not be uniform and entails considerable risk. If air is used for rewarming, the air should be strongly circulated around the frozen region. If the air is not turbulent in movement, some part may be overheated, and localized heating will occur and tissue may be permanently damaged. Short wave and ultrasound therapy which may be used with very superficial damage, provides a deep heating effect, and is even more dangerous than radiative heat. The use of ultrasound may result in mechanical damage to the tissue. The primary method for treatment should be rewarming in a water bath. It should be continued until the skin has a fresh, red color or for 25 to 30 minutes. If no color reaction occurs, then the tissue has been permanently damaged. Low molecular dextran and cortisone should be administered as early as possible to be of any value. During early stages of treatment, sympathetic blockage (or ectom) is also recommended by very competent surgeons.

There is only a little deposition of fibrin associated with freezing and there is no special requirements for heparin except at a later stage. Neither is there indication for vasodilating agents; there are probably contraindications even if they are injected intraarterially. Antihistamines or ACTH should not be administered. Pain relieving drugs and tetanus prophylaxis may be given. Antibiotics are probably only needed in deep infection. After the water bath treatment the frozen area, usually an extremity, should be elevated, with the moist air temperature at 25 - 30°C. The frozen area should not be bandaged or covered. Hydrophil cottonwool may be placed between the toes or fingers to absorb moisture. Swelling and blebs may develop rapidly and should not be opened. Treatment in water (34 - 37°C) is continued 2 to 3 times daily for 4 weeks, accompanied by frequent active movements. Crusts and dead tissue will loosen and demarcate, new skin will form under the blisters and the skin secretion will be removed.

Gangrene will rarely develop. The recovery process will be limited to dry necrosis, and the demarcation zone is adequate for surgery. Strict conservative treatment should be observed with surgery occurring only at the very last stages. The final result of rapid freezing is usually better than expected as the superficial parts may be black and perhaps seem necrotic while the deeper areas including the bone are viable. One reason for these favorable results may be that bones and deeper tissue do not actively vasoconstrict as well as the more superficial tissues. Thawing should not be attempted in the field if there is any risk for refreezing. It is then better to leave the part frozen as it is possible to walk on a frozen foot/leg and transportation is much easier. If a limb is frozen, one hour or four hours makes very little difference. The vesicles or blebs should not be opened or cut as the underlying thin epithelium layer must not be damaged mechanically or by infection. This tissue will give rise to the new skin. Some other methods for treatment have been suggested, but are not considered appropriate in this discussion.

In the field, practically all cold injuries are rewarmed in one way or another. A part can be warmed in the armpit, on the flexed elbow, in the groin, between the thighs, in the mouth, by direct body heat from another person (in sleeping bag, in bed), by warm water bottles, stones, sand, or enemas. Remember, a frozen part is insensitive to pain and doesn't react to overheating. Again, do not rub, massage, or bend the frozen area. Avoid manipulation and particularly traction in a swollen limb. Fractures should be treated later. Discourage smoking and, in moderation, alcohol may be permitted indoors.

It should be noted that wet, trench-foot type of injury can be treated in the same way, but there is a difference of opinion concerning therapy. Thawing is not needed of course and rapid rewarming may be not be required. If a bare hand freezes to cold metal, a warm liquid such as urine should be used to free the hand.

As mentioned, it is not possible to judge at an early stage what the permanent result of cold injury will be. In predicting results, favourable prognostic signs after thawing are: light red color, warm skin, rapid big swelling, with vesicles, and good sensibility. Unfavorable signs are: lasting cold, pale skin, cyanosis, no or slow swelling, blebs only proximal, small blood containing blisters, infection. A bloody exudate indicates poor prognosis.

*Treatment of hypothermia.* Rapid rewarming is recommended, preferably the whole body, in a water bath at a temperature 38–39°C. Water temperature of 44°C has been used in cases of deep hypothermia. If a water bath is not available, use carpets, blankets, water bottles, or sand bags. In hospitals, low molecular dextran, aramine bitartrat (0.3–0.5 mg. iv or 2–5 mg. im), isoprenalin (positive inotrop effect by betastimulation) may be tried by a slow i.m. or i.v. If the person is fully conscious, hot drinks may be taken. Rewarming must be tried even when respiration and the heart have stopped. Mouth to mouth respiration at a slow rate, not tracheal-intubation or positive pressure breathing, should be attempted. A rapid fall in pCO<sub>2</sub> can cause ventricular fibrillation. If heart massage is performed, use half the ordinary rate. There may be pronounced vasodilation and fall in blood pressure that indicates slower warming. Keep the patient's head low, and provide low molecular dextran intravenously, if possible. A striking fall in blood sugar may be seen. If blood tests for pH, electrolytes, blood glucose are taken, then glucose and saline can be given intravenously in the same venipuncture. Some glucose should be given. With therapy, there is considerable risk of heart arrhythmias and none of the ordinary antiarrhythmics are good. Xylocain (0.2% 20–40 drops per min) or Procainamid (slowly 0.7 mg/kg. min in 10 minutes) intravenously and later oral and intramuscular dosage should be tried. Rapid rewarming is considered the best therapy, but successful resuscitation has been accomplished with slow rewarming. Many advocate this slower procedure. Adequate sleep and food are important, but the patient must be closely observed. Late shock and sudden death is a threat.

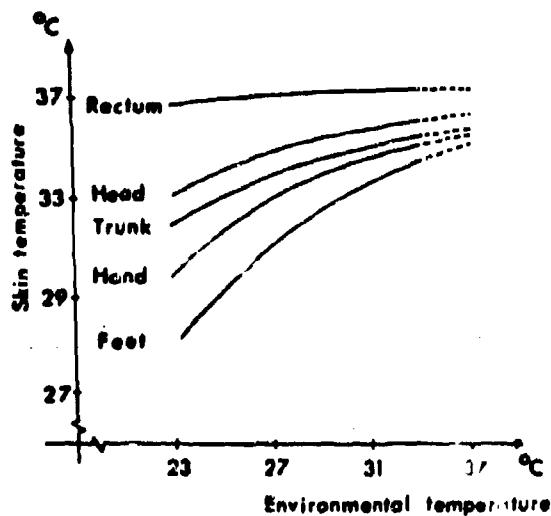
*Prevention of cold injury.* All factors which improve metabolism, heat balance, and protection, are of utmost importance. Of equal important is an accurate check of all equipment, and proper utilization of this equipment. Physical activity and conditioning is very important. Avoid sweating at all costs.

Voluntary tensing of muscles has little effect on the level of heat production. The psychological lift associated with warm food or drink is considerable.

The circadian rhythm indicates higher risk of cooling during the night. Antisweat drugs are not of value. The sweat glands will hardly be influenced. Use sleeping tablets, ataraxica with great caution, and no alcohol. Active movements of a part may, by pumping action, increase blood flow. At an early stage, hands may regain lost circulation by arm swinging so as to centrifuge the blood out. Flail the arms, stamp the feet and move around to enhance circulation. Too many socks or tight boots may hamper the circulation and the total insulation is reduced. Pressure points must be avoided. Metal with a high thermal conductivity should not be touched with bare skin. Most people know that the skin quickly freezes when placed against bare metal of machines or tools. But, many are not aware of and do not remember that gasoline, in a liquid state on a cold jerrycan, is extremely cold. Spilling of gasoline on the hands may result in serious cold damage. Ointment, containing nicotinic acid, histamines to open skin vessels have some negative effects and are not recommended. Wilson describes his Antarctic experiences that after breakfast, he took a tablet of Vasodil (tolazolin) as a vasodilator and had the subjective feeling that work bareheaded outdoors was easier<sup>4</sup>. Sufficient layers of fat applied to the skin in order to reduce heat conduction, should rarely be used – perhaps only on unprotected nose, chin and cheek. Psychic encouragement and incentives include: 1) hot drink without alcohol, and 2) perhaps a smoke.

In Norway, there are many sad accounts of people being surprised by bad weather in the mountains and later

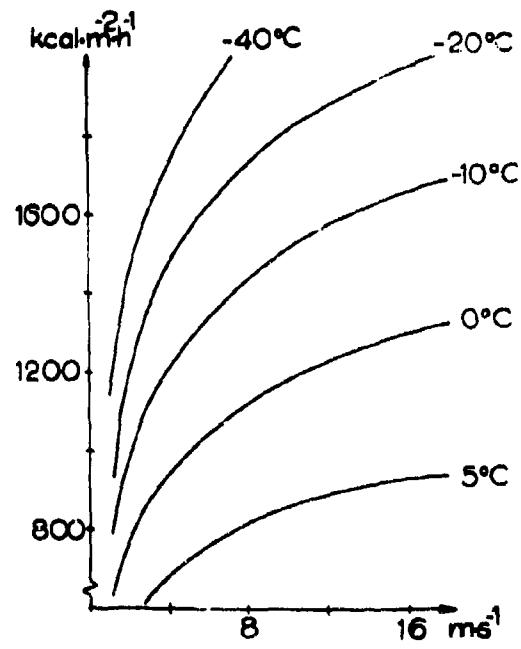
found dead although supplied with plenty of good clothing and food in the rucksack. One should have a sweater and trousers readily accessible inside an anorak in case of sudden fatigue or discomfort.



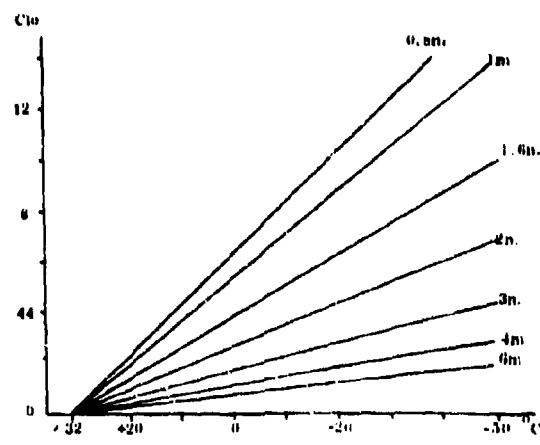
1 (a)



1 (b)



1 (c)



1 (d)

Fig. 1(a). Skin temperatures for various regions of nude subjects exposed to cool environments<sup>4</sup>.  
 1(b). The terminal vascular bed of the mouse ear is shown at room temperature and in five stages of cold-induced microcirculatory impairment. The arteriole is on the left and vein on the right of each schematic. From top to bottom, left to right we have 1) Normal, 2) Vasoconstriction, 3) Venular Dilation, 4) Focal Leakage, 5) Segmented Stasis and 6) A-V Shunting<sup>7</sup>. 1(c). Wind chill chart<sup>4</sup>. 1(d). Total insulation of clothing and air required for different metabolic rates. m = met<sup>8</sup>.

## PART FIVE

### CLOTHING

**General requirements.** In discussing clothing, many aspects must be considered, such as fibres, weave, insulation, permeability, absorption, weight, price, washability, strength, durability, fire resistance, adherence of snow, compressibility, elasticity, skin irritation, and ease of repair. Only a few of these factors can be discussed.

Thermal insulation will depend on the volume of entrapped air within and between the fibres and layers of the clothing. The insulation value of the fabric is usually only a small amount of the total insulation value. Therefore, for practical purposes, the insulation and its relative volume of entrapped air can be calculated from the thickness of the layers. The insulation or lack of it can be determined by infrared pictures. The thermal conductivity of the fabric can be measured directly in a "Clo-meter". Clo - for clothing - is the unit of insulation. One Clo is defined as the clothing required to keep a sitting subject comfortable at a temperature of 21°C, air movement 20 f/min (0.1 m/sec) with the relative humidity not higher than 50%. This corresponds to a metabolism and heat loss of 50 kcal/m<sup>2</sup> hr. One should also know if the measurement of insulation is done on a horizontal or vertical surface or on a flat or cylindrical clo-meter as there may be a significant difference because of convective currents. Ordinary street clothing is 1.0 clo with a shirt and pants equal to 0.4 clo, light underwear 0.4, and thick wool socks 0.7 clo insulation. "Tog" is another insulative unit which is equal to 0.75 clo. "Met" is a unit for metabolism. One met is equivalent to the normal resting metabolism. It is convenient to express work in these units, for example, horizontal walking (3.5 km/h) requires 1.8 met and horizontal running (15 km/h) requires 3.6 met. It is, therefore, possible to calculate the necessary clo required for the clothing (Fig. 1(d)) for a certain work and temperature condition.

**Moisture in clothing.** Considerable effort has been devoted to increasing permeability of a fabric without decreasing its insulative value. Surprisingly, often there is little correlation between air porosity and vapour permeability. Vapour passage from the skin is usually accomplished by convection with some conduction. Hydrophilic synthetic fibers will spread the water in a thin film. If the fiber does not absorb much moisture, the fabric will be easy to dry, but will feel cold.

In extreme cold, condensation occurs within the clothing or in a sleeping bag. A distinct condensation zone can be observed in which moisture is condensed and frozen. The reason for this is that the absolute vapour pressure decreases from the skin outwards, but the decrease is not enough to keep pace with the reduction in saturation pressure as the temperature is decreased toward the clothing surface. The condensation will rapidly exceed what the fibers and fabric can absorb and a visible frostline is formed. This frost will accumulate in the clothing unless it is eliminated by shaking or drying. The vapour permeability and moisture characteristics of the fabric will affect profoundly the thermal insulation.

Moisture in clothing is often very dangerous in wet cold conditions. It is easier to protect oneself against extreme, dry cold, when the moisture in the ambient air is extremely small, than against a wet cold associated with slush or rain. The worst condition is probably when extreme dry cold is encountered at night after wet, cold daytime conditions.

**Clothing should not hamper movements.** Fit should be loose in the axilla, between the thighs, and in the buttocks regions, to ensure free movement. The clothing must have some thickness to allow pumping action of the moist air, both through the fabric and through ventilating holes. The layers should slide easily over one another to facilitate dressing and movement, but static electricity is generated on the surface of many synthetic materials. Clothing must of course be contour fitted to the shape of the body. Often underwear is too tight. A loose pyjama-like fit is better and facilitates evaporation of sweat. Outer garments should be *easy to open* to allow moist air to escape from the body surface. Dirty, oily clothing reduces the insulation value and must be laundered. Clean socks are an absolute necessity.

Many people feel a dark colored fabric absorbs more incoming solar radiation than lighter colored materials and therefore is warmer. More thermal energy is present in the near infrared invisible part of the spectrum, than from the visible. It should also be remembered that the surface which absorbs much of the incoming energy (low reflectance) has a high emissivity. Black color only means that the visible rays are absorbed, while a white fabric may absorb more energy than black fabric, if absorption in the infrared spectrum is high. Many arctic animals and birds are white during winter time. The absorption and emission of radiation (visible and infrared) between clothing and the sun is a very complex matter.

New textiles are now manufactured which consider absorption and radiation. Orange or red windbreakers are extremely visible against any background and may be an advantage in survival situation. Strings, straps and elastics often hamper the peripheral circulation and may reduce the ventilation and exchange of air. Suspenders should be used to avoid this problem. If a rucksack is not worn, it would be better to dispense with the suspenders to allow good convective ventilation from the upper torso. Two strings should not lie over the same area, but should be placed at different heights.

*Clothing composition.* Wool fibers have excellent qualities such as a spiral shape and relative stiffness under wet conditions. Wool fabrics will entrap air and provide good insulation even when wet. The fiber, which is a protein, can absorb up to 33% of its weight in water, part of which is chemically bound (hygroscopic). The fiber surface is hydrophobe, not wetable. Vapor which is condensed in the outer part of the clothing will form droplets on the hydrophobe fiber and will not penetrate. On the other hand, a hydrophilic (synthetic) fiber surface will spread the water as a film as well as allow penetration in toward the body. Many garments made of cotton and synthetic fibers feel soft, but under wet conditions, feel cold.

The textile industry is undergoing enormous development and has produced new fibers, preparations, and types of weave. Plastic, and man-made materials have been introduced. In many cases, these new materials have replaced the traditional natural materials. Fur, though warmer for any given weight, is expensive, awkward to sew, and difficult to clean. Feathers and hair are also excellent insulators. Many of the new fabrics offer great advantages such as lower cost, greater strength, and durability, convenient washability, and high insulation per weight. All cold weather garments, natural or synthetic, should pass laboratory and field testing before being used.

*Clothing principles.* A garment worn next to the skin entraps a layer of air when the person is quiet, but should allow air to be pumped out when he moves. This feature is of special importance on the trunk which is more difficult to ventilate than the extremities. "Brynjel" (string-vest) undergarments are ideal for this purpose. This net material, originally knitted with large meshes of stiff, thick yarn, does not absorb moisture. A recent innovation has been to weave vertical channels that pass the moist air up and out through the neck opening (Fig. 3(d)). Over the "brynjel", various insulating layers are worn such as shirts, sweaters and a windshield. This windshield should ventilate, allowing vapor to pass out, but prevent water and wind from entering the clothing. It is not always possible to satisfy both criteria under changing conditions of humidity, wind and temperature. More insulation is required as temperatures fall and tighter fabrics are required for windy conditions. With no wind, a windbreaker is unnecessary. Experience is necessary to make the best choice under prevailing conditions. Most people, in spite of this knowledge, overdress and wear clothing that is too tight. If a person is physically fit, then it is best to dress so as to feel somewhat chilly. It is better to wear several thin garments than one thick one. A single garment cannot be considered by itself as it is a part of the total clothing assembly. The most exposed body areas such as the front of shoulders and the thighs, should be well protected (Fig. 2(c)). At present, clothing has the same clo-value between the thighs and under the arms as on the shoulders.

Openings in the clothing such as buttons, hooks, velcro fastenings are very important thermally, and should close easily when dexterity is limited by mittens or cold fingers. A leather thong attached to a zipper is very useful. Nothing is so easy to open and to close rapidly in front as a garment with a zipper. In stormy weather, this feature allows rapid donning (Fig. 2(d)).

*Articles of clothing.* Anorak (parkas) with hood and trousers are essential in windy conditions. Sufficient width is necessary so that it is easy to don over other clothing. There should be horizontal circular elastics or strings for tightening the garment around the body. The neck and waist of the garment can be loose to allow pumping and ventilation. Large front pockets add protection against cold and moisture. The pockets should be easy to open or close and may be of the "self-closing" type. The hood must have a string (fixed at one point) in a channel for tightening around the face. The string must have a practical stopper/lock easy to open and close. The hood must move with the head at rotation and flexion. The hood opening for the face should not interfere with the wearing of goggles. When the string in the edge of the face opening is pulled, the opening will become circular and restrict vision in the upper, lateral quadrant. This also leaves part of the forehead exposed resulting in significant heat loss and considerable pain when snow/ice crystals blow against the face (Fig. 3(a)). A segment of fabric should therefore be sewn on to the edge of the face opening to cover the front down to the goggles. The opening can be made tunnel shaped with an adjustable flexible metal wire and of different materials (Fig. 3(b) and 3(c)).

Personally, I am not in favour of a loose hood. Instead the hood should be sewn to the anorak so that it is readily accessible for use. The outer anorak should not have openings in the front except for the face and neck, and is thus donned over the head. A wedge of fabric sewn in at the wrists will allow a large opening when this is required but has buttons for full closure. A circular knitted wristseal is not possible to open, and provides little aeration. Because the anorak will often be used without wind trousers, it should have a triangle of tight fabric in the pocket which can be buttoned in the groin region for protection (Fig. 5(a)). If wind trousers are worn, there should not be a gap between the trousers and the boots at full flexion in the knee, and it is advantageous to have trousers wide enough to don with boots on. Loose elastic under the knee offers some ease in movement. Warm, full body sized protecting garments are made with openings and zippers arranged so that they are possible to take on without removing boots or skis, which is practical after physical exertion when one is numb.

Since hair is a good insulator, any covering such as a cap can be light, and simple. A cap should have inside flaps for protection of the ears, and forehead (Fig. 2(d)). A knitted cap or "earwarmers" may be practical and sufficient for most conditions when a hood is also worn. I think people have too much insulation on the head and is not required as the skin on the head is highly vascularized and brain temperature does not fall except under general hypothermia.

The head and neck are highly vascularized and heat loss in the cold may be very large from these areas. Therefore, adequate protection of the head and neck is required to conserve heat. A face mask would protect against frostbite but a good face mask has not yet been designed. Condensation and ice collects around the mouth and nose opening of most masks. An extra "headover" or the "balaclava" type for protection is recommended (Fig. 5(c)).

A sweater with a high collar is fine to protect the neck but a wool scarf about 80 cm long is just as good. A scarf is easy to pack, use, and take off. A square-shaped cloth may be more versatile than a long scarf and equally functional.

For leg protection, the knee type (knickers) with suspenders is recommended that has a double-layer of material in front of the thighs. They should not be so high waisted as to hamper respiration. The buttons for the suspenders must be sewn on the outer side to avoid chafing. The thigh length is important and it should allow full flexion of the knee with minimal width. Long, ankle length trousers will get wet, dirty and wear prematurely. Gamaches must be worn with long pants. If long trousers are worn, some binding such as a loose elastic band should be worn under the knee to keep sufficient fabric above the knee for free flexion. A long, wide outer coat can be worn and also used as a sleeping bag.

The protection of the extremities is of utmost importance. The knitted gloves or mittens must pull over the wrist to avoid any gap, while the fingers can warm each other. Short mittens may be practical if long "pulse-warmers" are used to protect the wrist and lower forearm (Fig. 2(b)). Mittens should fit the fingers in a flexed position (Fig. 2(a)). If the fingers are straight, very often they will be too long and will contain too much air on the dorsal side and allow excess convective pumping. Mittens should be large enough so the thumb can be placed next to the fingers for warming. A "shooting finger" or any opening in a mitten that allows one or more fingers out for finer work may be practical. Additional insulation should be provided on the dorsal side to protect against cold wind and rain. Special outer, wind protective mittens that extend up the forearm with tie straps is mandatory. These outer shells should allow room for two pairs of mittens.

Foot gear is perhaps the most important part of any clothing assembly. The length of socks is important and should fit the trousers snuggly. Many persons prefer socks that pull over the knees. Whether this has merit thermally, is unknown. Two or three pairs of thin socks afford better insulation than one thick pair. Often socks are too tight around the upper calf. As socks will get damp inside the boot, short socks should be worn and changed frequently. These can be combined with "loose legs" or with thinner, longer, socks. (Fig. 4(b)). Then moisture can easily evaporate from the calf of the legs. A "foot cloth" was previously used instead of socks in the armed forces and can be very versatile and practical. (Fig. 4(d)). These wrappings are cheap and easy to dry. Training is required to don them correctly. To prevent sore feet and blisters, short silk or nylon socks should be worn next to the skin. These socks are durable and easy to wash. Socks must of course be mended. The inner side of wool socks should be inspected and "wool pills" removed.

Boots should be worn for some time and must fit well. New boots should not be worn in cold conditions. Tightness and pressure points are the most important factors promoting cold damage. One pair of socks may even be warmer than two. Only personal experience can dictate how wide the boots must be for comfortable movements, massage and ventilation of the foot. Boots should be easy to remove so that tape can be applied to any sore region. Extra pressure points as with hammer toes or hallux valgus greatly increase the risk of foot problems. Many persons prefer boots with fixed sewn inner lining, but this lining is quickly compressed and loses its insulative value. A worn out lining will often lie in folds. Short socks should be preferred instead of lining; they are easy to change, to dry and to repair. Leather soles are often very slippery, and should be "patterned". Nails used for mechanical protection of the boots will reduce the insulation and tear the leather. Rubber boots are fine for wet cold conditions, but have a high heat conductance and do not provide adequate ventilation. Fit is important in these boots as there is no "breaking in". Boots with fur, hair out, are excellent for dry cold but are at a disadvantage in wet conditions (Fig. 4(a)). Large insulated boots, the vapor barrier boots are excellent, but are too clumsy and impractical for long walks and for skiing. For skiing, special boots are preferred. In camp mucklucks, foot bags of canvas, plastic or other material, are very useful (Fig. 4(c)). "Skallers" are fur boots from sculls of reindeer and are used commonly by Lapps. Other material which may be at hand are paper, cloth, grass may add to insulation and comfort in emergency situations. Special precautions and equipment are needed for ice crampons. For skiing, when bindings cause a tight fit to the boot, some extra insulation is often needed. There are many types of cover to put over the outside of the boot for this purpose. In Scandinavian countries they are called "ladde" (Fig. 4(c)). In dry cold, a part of an old sock pulled over the front part of the boot is practical and cheap. One can use several layers, and snow adhering to the outer side of "ladde" will contribute to the overall foot insulation. Toes require the most insulation. For wet cold, a galosh-like thin cover of rubber provides excellent protection. A removable insole of porous, incompressible material with some moisture-absorbing material is an excellent insulator and can be changed whenever the socks are changed. Boots must be treated with special care and dried with a moderate, non-radiative heat. They

should be polished and greased. In the design of military clothing and boots, proper consideration should be given to the principles mentioned above, even if the garments are primarily designed for their military function.



2(a)



2(b)



2(c)

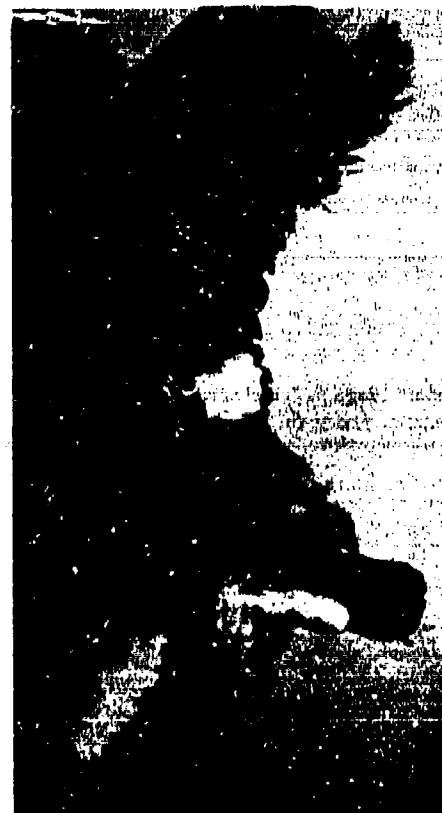


2(d)

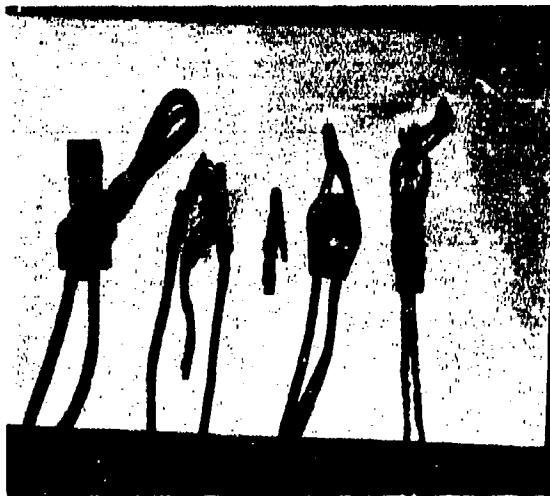
Fig. 2(a). A synthetic mitten shown on the left is thick and warm but has poor ventilation through the outer layer. The mittens on the right are knitted in the preferred flexed position. Note the leather watch band. 2(b). Top. Two slits in the mittens provide fine tactile discrimination. Middle and Bottom. Improved "pulse warmer" and half-mit from a sock or sweater. 2(c). This windjacket has double fabric covering the shoulders and upper torso with large pockets. A "balaclava" is worn on the head. The person has a short rubber tubing in his mouth for drinking. 2(d). This jacket has a full length zipper which is well protected and large pockets with flaps. A knitted wool ear warmer is worn. The subject is holding a cap with inside flaps for ear protection.



3(a)



3(b)



3(c)



3(d)

**Fig. 3(a).** This "anorak" can be opened from the face down to mid-breast. The design of the hood is poor as the hood does not cover the forehead and the hood opening is difficult to close. **3(b).** Wolf or wolverine fur hood trim provides excellent insulation and the best protection against accumulation of frozen condensate. Fur mittens afford excellent insulation but are clumsy. **3(c).** Different locks for hood drawstrings are shown. The crocodile fasteners (middle two) can also be used in a garment with a full opening in the front. **3(d)** "Brynje" vest with vertical channels to permit convective pumping up through the neck.



4(a)



4(b)



4(c)



4(d)

Fig. 4(a). Left to right. Lapp footgear made of reindeer skins, a felt boot, a felt sock and a sheepskin sock. These foot coverings are only suitable in dry cold and for use in camp. 4(b) A short sock is worn on the left foot for easy changing and is combined with a long, loose sock on the right foot. 4(c). A plastic bag is placed over the right boot for added protection. A "snowlock" is placed around the left leg for skiing. An "ladde" is made of an old sock placed over the toe of the left boot. 4(d). A foot cloth is being wrapped round the foot to provide emergency insulation.



5(a)



5(b)



5(c)

Fig. 5(a). A triangular piece of material is placed over the genitals for additional insulation and to keep the shirt openings closed. 5(b). A primitive stove is made from a can. Holes are placed in the lower half for better air circulation. Sand, or cloth may be used as a wick for the oil - animal fat fuel. 5(c). A loosely knit, stretchable "headover" is worn over the head of the subject on the left and as a scarf on the one on the right.

**PART SIX**

**SHELTER, CAMPING AND SURVIVAL EQUIPMENT**

*Location.* Selection of an appropriate campsite is important and requires experience. Snow conditions, ice, trees, bushes and wind are of great importance. In valleys, the temperature during the night may be considerably lower than higher up on the hillside. This temperature inversion occurs in quiet, clear weather. Usually it is warmer the closer one is to the ground. However, it may be colder in snow covered terrain if the temperature on previous days was very low. Sand, stone, rock will conduct heat and will be cold. At times it is best to have snow under a tent to make a smooth, sleeping surface. During springtime and summer, in permafrost areas, the sun will melt the upper part of the soil and it will be wet and very soft.

The insulation provided by tents is increased considerably if the walls are of double fabric containing a thin layer of air. With a single layer wall, the temperature inside will be almost identical to that outside. In such a case it is better to dig a snowcave. The fabric in the tent can be very light, such as nylon, and the pole or framework made of glass fiber. In some tents inflatable air canals provide a rigid support and are lightweight compared to tents with poles but are very vulnerable to damage. A minimum of two ventilating holes may be provided in the walls. Pockets on the walls are convenient as it allows one to find things in darkness. A string under the ceiling provides a means for drying boots. It is practical to have a loose piece of fabric in reserve as extra cover for the roof. In the event of a storm, it can be placed over the tent and tightened to reduce the height and wind resistance of the tent. The floor should be of strong, watertight fabric and a small opening for urination can be provided. Some loose snow may be shuffled up on the outside, and some snowblocks should be placed at an angle to provide a wind break. All snow adhering to the clothing and to the boots should be removed before entering the tent.

*Snow Caves.* A snow cave is the best cold weather shelter to make in emergency situations. Wind, snow conditions, and natural slopes will dictate where to dig. There may be sufficient deep snow in a tree free area, or on the lee side of a slope (Fig. 6(b)). On the lee side of stones, snow may heap up in big drifts offering a good place for digging a snowcave and cutting snowblocks. There may be very little snow close to large rocks, as it blows around the rock and is a poor place for a shelter. Peripheral to this, however, on the windsides, the snow may be deep and fine for digging. The same can be the case under and around trees (Fig. 6(c), 6(d)).

After probing with a stick to determine if there is adequate snow depth, one should start digging high up on the slope with a walking access from the side. The slope under the opening will allow the excavated snow to fall and roll down the slope. If the opening is too low on a slope it is much more difficult to remove the snow. One should dig in horizontally and upwards. Remember that the entrance to a cave should be from the floor to trap the warmer air inside and to prevent the cold heavy air from entering (Fig. 6(b)). Final closure of the cave, must be done from inside. This means that the upper part of the opening which is used while digging must be closed and the best snow-blocks should be reserved for this purpose. Considerable snow will fall and accumulate on the lee side where it's relatively still. Therefore, the entrance to the cave will often be closed by drifting snow. The ceiling should be curved smoothly and provide no "dripping nose". A "bed" or "chair" is made higher than the floor to avoid the coldest air on the floor. To avoid melting, a burning candle or stove should not be placed close to the walls or near the ceiling.

Under difficult conditions, a small cave will suffice, but it is better to make a large snow cave so as to be able to stand upright to stretch, exercise, and increase heat production. The smaller cave is better for heat conservation, but because snow is mostly air, the size probably makes little difference. Several people may make "castles" in the snow. While digging, the shoulders and the back should be protected against snow falling from the roof. It is hard work but try to avoid sweating. A spade, snowsaw, snowknife, oars from the dinghy, skipoles, twigs, hands, all can be used for excavation. Snowblocks should be cut to fit the upper part of the opening. Skis, twigs, branches, or any fabric can also be used. The cave should be marked on the outside with a ski or a pole to attract the attention of a search group. Rescue aircraft can not be heard from inside the cave.

One or two holes (3 to 5 cm diameter) must be made in the roof for ventilation. A single burning candle, which should be part of the emergency pack, can increase the temperature inside the cave several degrees. The temperature should not be higher than minus 2°C. If it is, the water in the walls will freeze, and make the cave tight. This can be an advantage in a storm, but it may be a great risk if cooking is done inside, and if the ventilating holes in the roof become plugged. The holes must be kept open from the inside. Cooking should as a rule be done at the cave entrance or outside the cave because of possible problems with carbon monoxide. If it is blowing, holes in the roof will insure good ventilation, and on the first night when there is only loose snow in the walls, there will be adequate

aeration without holes. The unexperienced person should be very careful. It is better to feel cold and awake than to go asleep and be killed by CO. Those who have never dug a cave and stayed in it overnight do not appreciate how effective a snow cave is as a thermal barrier. The temperature inside a snow cave will be much higher than in a tent, it is very quiet with no tent wall noise. If you have a tent, it can be set up inside a snow cave. It takes a significant period of time and energy to dig a snow cave, but it is well worth it.

Meteorological balloons have been used in moderate cold to make a snow cave. An inflated balloon is placed in a depression in the snow and covered with snow to a depth of at least one foot. After some hours, the snow is recrystallized, hardened and the shape is fixed. Then one tunnels through the lower part of the snow mound, the balloon is deflated, removed, and the cave is made. A snowblock igloo is another excellent shelter, but it requires special snow conditions and is very difficult to build. It can be used for a long, semipermanent shelter. In forested regions, it might at first seem easiest to camp under snow-covered branches, but it is not. Snow will fall on you as a fire warms the air and there are always openings between the branches so as the warm air rises, cold air will enter.

A downed aircraft with good insulation may be used as a shelter, but the metal hull will soon become "cold soaked" and will be colder than a snow cave<sup>9</sup>. The advice "stay by the plane" is valid only as part of the wreckage may be useful for sighting purposes. Huts built partly or completely by stone, blocks of turf, or soil, may also offer some advantage. A lean-to is not worth the effort to build. In an extreme emergency a parachute can be used as a tent. One layer does not provide any insulation, but two or more layers does provide some and can be arranged as a one-man tent. The shroud lines are invaluable and must be kept.

*Floor coverings and sleeping bags.* Anything at hand can be used to keep the body up off the cold ground or snow-straps, dinghy, seatpack, parachute, paper, twigs, moss, grass or hay. Pieces of foam plastic and other incompressible materials are effective and the dinghy, anti-g-suit, or MaeWest may serve as an air mattress. Incompressible materials should be placed under the shoulders, buttocks — the main pressure points of the body. Placing a water impermeable layer under the body will keep the clothing dry, but moisture from the skin will condense on the fabric and the body will lose heat by conduction. If an air mattress is available, be careful with inflation as moisture in the expired air will accumulate and freeze. Use a piece of tubing or foot pump. An air mattress should be of multi-horizontally layered construction to prevent convective heat losses. The new closed cell sponge mattresses provide good insulation even under pressure areas.

The down filled survival clothing provides excellent insulation but is vulnerable to tears and holes from flying sparks. The wide jacket or outer long coat allows the arms to be held next to the body and can be combined with the short foot bag (elephant foot) for sleeping. A mylar reflective coated rescue blanket can be wrapped around a person to provide a radiative, convective barrier. The ordinary parachute can be folded to form a sleeping bag or cover. Many layers of fabric with some entrapped air or grass, leaves, paper, can be effective, thermally (Fig. 7(d)). Such a "sleeping bag" can be placed in the inflated dinghy and provide shelter which is easy to arrange even under emergency conditions for an injured pilot. Inflate the floor and cover of the dinghy and kick away some snow to provide a small still layer of air underneath. Some may prefer to cut a hole in the cover to be able to stretch out the legs but it will be colder. It is relatively easy to provide insulation over the body. It is much more difficult to provide appropriate insulation under the body. Prepare for this.

A sleeping bag is of paramount importance, and factors such as insulation, weight, price, durability have to be considered. An eider down bag is very light and warm but expensive. To prevent moisture from entering into the down, both inner and outer sides of the bag can be made of water tight material. The size and shape of the upper opening is important. Some prefer a circular opening at the head end with a drawstring (Fig. 7(c)). One can enter in a standing position, but this is difficult if a person is hurt, and many recommend a zipper along the side of the bag. If vacuum packed, a bag requires only a small volume. Fine down and other fragile materials should be treated with great care to prevent damage. Many new synthetic insulative materials are used today and are less fragile. Often sleeping bags are too big and contain too much air. With body movements, air will be pumped in and out of the bag and considerable heat will be lost. A smaller, snugger fitting bag will prevent this convective loss. Some very loose elastic straps around the outside of the bag can be used to reduce the circumference.

Little additional clothing should be worn inside the sleeping bag because clothing may contain a great deal of moisture. Only a cap on the head and socks on the feet are recommended. An open meshed cotton cloth may be used to protect the face against the cold and "snow" falling down from the ceiling of the tent. The bag should be ventilated whenever possible during the day, as there will usually be moisture in it. It is warmer for two men to lie side by side under two blankets — or in one bag — than a single person by himself. Doubling up saves weight and conserves body heat. Sit or lie close together whenever possible.

*Wet clothing.* Considerable heat is removed for every gram of water evaporated (550 cals for the evaporation of 1 gram of water at 35°C). Therefore, it is very important to keep all clothing and sleeping equipment dry. Socks and other clothing can be dried in front of the thigh while walking or under the trousers. Frozen stiff boots should be placed inside the sleeping bag in the morning for easy donning. But, moisture will condense in the bag. Be very careful about drying boots by radiative heat in front of an open fire as there is considerable risk of overheating boots. If this happens, the leather will shrink and the boots will be useless. Therefore, the boots must be kept a long distance from the fire with good air circulation. To dry boots, unlace and open them fully. Dry grass, hay, paper,

warm sand, or stones may be placed inside. To avoid overheating, the small stones may be warmed in water. Sennac grass absorbs considerable moisture and may be reused by drying the grass on the body or elsewhere.

If someone falls in cold water and no dry garments are available, the wet clothing should usually be taken off and twisted hard to remove the moisture even in cold temperature. The value of lying down in loose snow and rolling to remove excess water from clothing is questionable. A cover of ice on the clothing will provide some advantage in cold, windy conditions. If water runs down into a boot, immediately lie prone, lift the leg vertically so that the water runs "up" the leg, where it may dry. Water inside the boots may be partly dried out with a cloth. Remember when wet clothing is hung on a string over a fire, be careful it doesn't fall into the fire. Many tent fires have started in this manner.

**Fire, Heat, Light.** Matches are required. Storm matches are good, but not needed. Many different stoves and cooking equipment are available and suitable for gasoline, petroleum, oil, or alcohol fuels (Fig. 5(b) and 6(a)). Melted animal fat may be used for fuel. At very low temperatures, the vapour pressure will be so low that the match must be held very close to the fuel for ignition or the cup for the fuel should be slightly preheated. It is an art to make a fire in extremely cold conditions with moist, icy wood and meager equipment. Considerable training and experience is needed. The lowest, small twigs on trees, bark cut off from trees (birch), dry moss, grass, lichen, roots, turf, or fire tablets may be used as starter. Logs found on the shoreline are often dry. A knife or axe can be used to provide fine kindling. The fireplace should be well protected leeward and on the sides with stones, moss, or turfs. Do not try to make the fire directly on snow. A good underlying surface is needed so use logs, stones, turfs, or bare ground. If paper is at hand, do not use too much. Keep the kindling bark, concentrated, use small pieces — press it together. Split the wood. It often pays to keep some kindling wood or bark on hand so it may quickly be added. The access of air should be very low at first when you start the fire. Keep the air warm. Spruce usually throws more sparks than pine and birch.

Be careful with your equipment, synthetic fabrics are easily damaged from flying embers. When cooking, the flame should surround the cooking pan. If it doesn't, there is considerable cooling on the upper part of the pot and heating/cooking is difficult. At night, the embers can be covered by turf, or wet grass so that starting a fire will be easier in the morning. Do not make a fire near big tree roots as there is always the risk of starting forest fires. Always make sure a fire is completely out before leaving. In wintertime, small trees are relatively dehydrated and it is possible to use short pieces for fuel once a small fire is burning well.

Remember and prepare for emergency fire signals at night and smoke signals during the daytime. Figure 8(c) shows the accepted code for downed aircrew members<sup>10</sup>.

**Carbon Monoxide (CO).** Carbon monoxide is formed by incomplete combustion of carbon. In complete combustion, carbon combines with two atoms of oxygen and carbon dioxide is formed. The reasons for incomplete combustion are low ambient temperature and lack of oxygen. There is a high risk of CO formation when a flame hits a cold surface, for instance when melting snow. As the cooking pot becomes warmer, there is very little risk. A high concentration of CO burns with a blue flame, but this may be misleading as blue flames result from the combustion of other fuels. CO occurs in the glowing part of the flame. CO is not heavier than air. When a high concentration of CO occurs near the floor, it is because of low ambient temperatures and the source of combustion is low. At higher temperatures, CO will rapidly diffuse.

CO is poisonous because its affinity to hemoglobin is very high, so normal O<sub>2</sub> transportation by the blood is reduced. It is also toxic to the cells and the oxygen dissociation curve is displaced to the left. This means that the unloading of O<sub>2</sub> from the blood to the cells is also reduced. In addition, CO accumulates in the mitochondria-rich organs and tissues. The uptake and the elimination of CO is faster when the body's respiration and circulation is accelerated under strain and excitement. A concentration of CO in the air of 0.04 vol % for some hours may be lethal.

There is no characteristic single symptom of CO poisoning but sudden headaches, weakness, nausea, sleepiness, and perhaps heart palpitations may occur. The most striking symptom is dyspnea (shortness of breath) with the least exertion. This is caused by the low volume percent of O<sub>2</sub> in the blood. If the CO concentration is high, the skin color is red because CO hemoglobin is bright red and there is no cyanosis in striking contrast to respiratory distress after exercise. It is stated that more people have succumbed in the arctic because of CO poisoning than of hypothermia. The primary cause of these fatalities is the production of CO from burning fires or stoves inside of tents or caves or small primitive rooms without proper ventilation. If any flame is present, you should remain awake, especially in a confined area such as a snow cave.

Successful resuscitation of persons exposed to high levels of CO has been accomplished even after long respiratory and circulatory cessation. Artificial respiration and heart massage should be performed even if it seems hopeless. Administer pure oxygen if it is available. Prevent heart arrhythmias or shock and avoid cooling if at all possible.

**The match test.** A flame of a match will be lower when the oxygen percentage is reduced and will be extinguished at 16–14% oxygen. The reduction of the flame does not depend on the concentration of CO<sub>2</sub> nor on CO. The size of the flame has however been used as an indication for CO present. This may be correct because a small flame means

low oxygen which means increased risk of CO formation. The flame may however be small and extinguished without any CO present or the flame may be high with high CO levels present. Strong soot may also indicate the presence of CO but not always. For example, soot occurs when cyclic compounds are burned.

**Smoking.** Many problems such as peripheral vasoconstriction and sweating are associated with smoking. Dry cold air combined with smoking may cause a reaction of the mucous membranes of nose, or bronchi. Coughing and a restless sleep may follow. The psychological importance of smoking and wellbeing may offset these disadvantages for many people. Therefore, used as a stimulant, smoking may be of some importance and it does not contribute significantly to an increase in cold injury.

**Survival Equipment.** In deep snow, snowshoes should be improvised for travel. Branches from birch or pine trees are excellent for the frame and they can be tied together with parachute chords. Small branches can be bent even if cold-soaked, but the thicker limbs must be warmed and often incised on the concave side before they are bent. It is usually easiest to walk with a long narrow snowshoe than with a broader one. (Fig. 8(b), and 8(d)). They should be sized and shaped according to snow conditions. The string inside the webbing of the parachute cords is preferred for the foot pad. If available, short, light plastic or wooden skis are useful under many conditions.

There has been no standardization for a survival pack. Different countries have their own survival pack and the contents vary. Some basic points about emergency rations, clothing have already been discussed. Some possible components are shown in Figures 9 and 10.

The design and size of the rucksack will not be discussed but a few points should be mentioned. The center of gravity of the rucksack should be as close to the body as possible, but there must be an open space between the sack and the back of the person for ventilation. To pack a sack requires experience. I recommend the following system. Place the sack so that you face the front side. Put those articles that have to do with the head and upper part of the body in the left side of the sack, and those pertaining to the feet in the right side of the sack. Mittens and some food should be placed in an outside left pocket. Things for immediate repair of the skis can be placed in the right outer pocket. This will help you find things quickly, even in the dark. Do not pack the sack until you have everything in front of you. You should have what you need during the day on top of the sack and what you only need and use in the shelter in the bottom of the sack. Outside on the sack you should have safety pins and tape as they will be needed frequently.

A person should be required to have attended a first aid course and be familiar with the contents and use of survival first aid kits. Shock or any injury is potentially more hazardous in the cold and should be handled accordingly. For example, traction and reposition of fractures will often reduce blood supply and should be postponed until a warm shelter is reached.

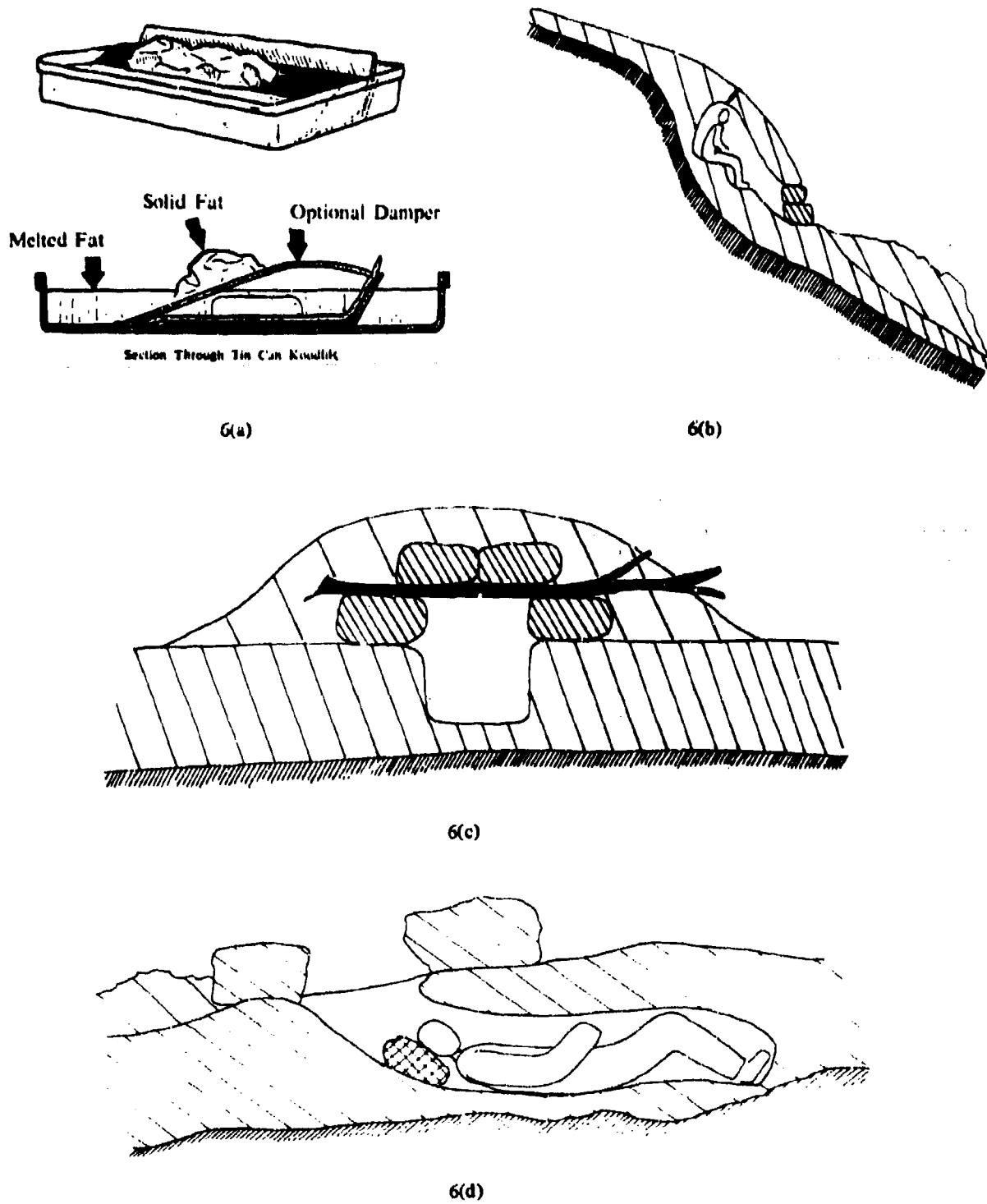
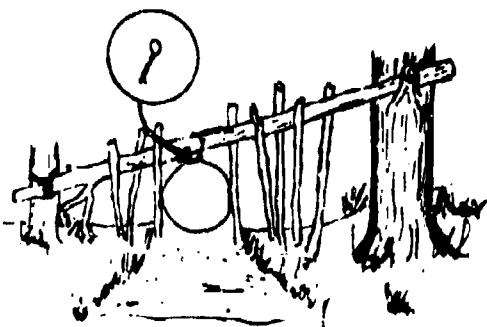


Fig. 6(a). An eskimo "koodlik" made from a flat can. Animal fat is melted by the flame. A wick lying in the melted fat leads the fat up to the flame. 6(b). A snowcave built on a steep slope. 6(c). A snowshelter made on flat terrain by digging a snow trench and covering it with snow blocks and sticks. 6(d). A snowcave built in a drift with blocks of snow as a windbreak.



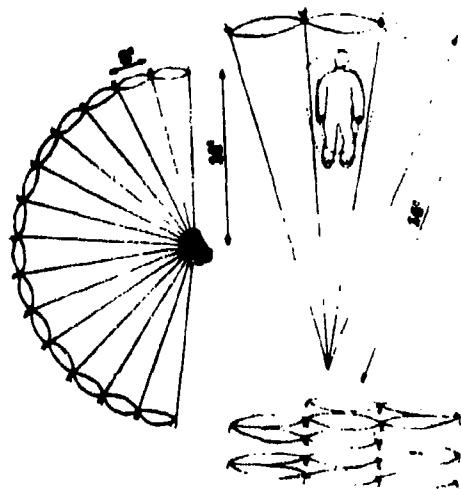
7(a)



7(b)

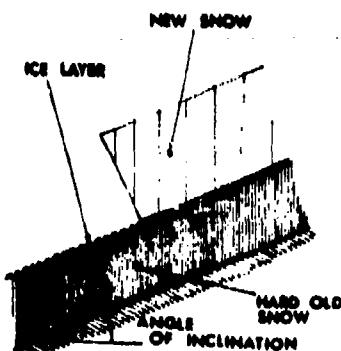


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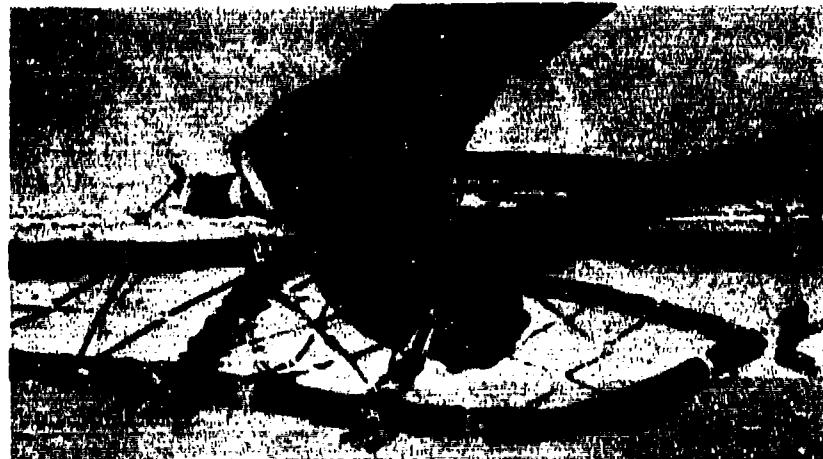


7(d)

Fig. 7(a). A wire snare for trapping hares or other small animals. 7(b). Protection against sunburn, side eye shades, paper nose protection and tape to prevent chapped lips. 7(c). Two methods of partitioning insulation in sleeping bags. The type of construction on the left allows less packing of the insulation, but does not prevent it from sinking down. 7(d). The use of a parachute to make a sleeping bag.

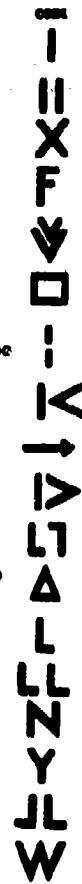


8(a)

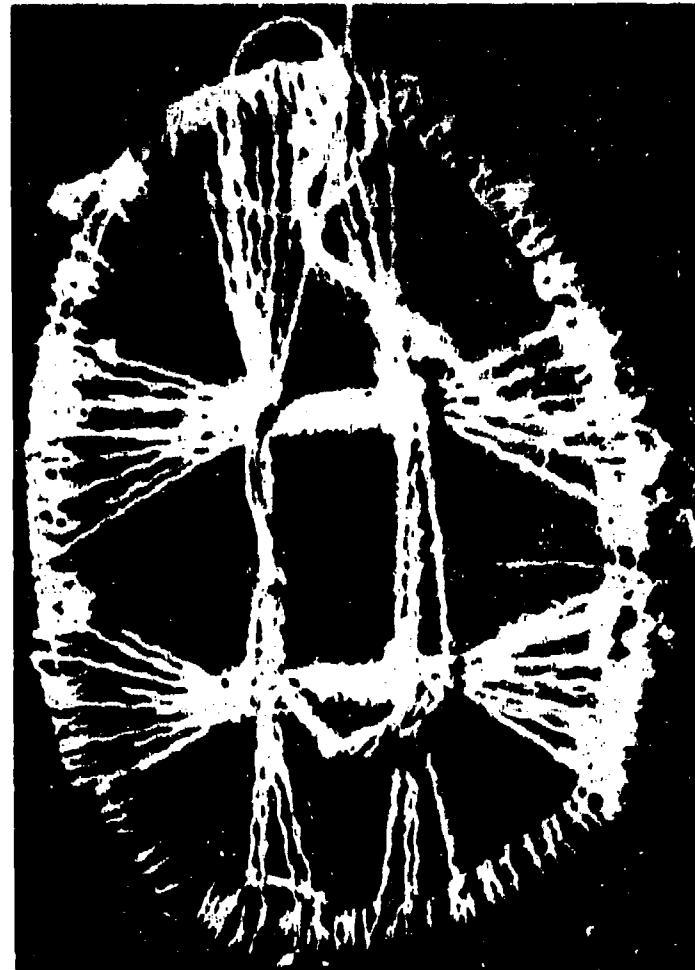


8(b)

- 8(c)
- 1 REQUIRES DOCTOR  
SERIOUS INJURIES
  - 2 REQUIRES MEDICAL  
SUPPLIES
  - 3 UNABLE TO PROCEED
  - 4 REQUIRE FOOD AND  
WATER
  - 5 REQUIRE FIREARMS AND  
AMMUNITION
  - 6 REQUIRE MAP AND  
COMPASS
  - 7 REQUIRE SIGNAL LAMP  
WITH BATTERY AND RADIO
  - 8 INDICATE DIRECTION TO  
PROCEED
  - 9 AM PROCEEDING IN THIS  
DIRECTION
  - 10 WILL ATTEMPT TAKE OFF
  - 11 AIRCRAFT SERIOUSLY  
DAMAGED
  - 12 PROBABLY SAFE TO LAND  
HERE
  - 13 REQUIRE FUEL AND OIL
  - 14 ALL WELL
  - 15 NO
  - 16 YES
  - 17 NOT UNDERSTOOD
  - 18 REQUIRE ENGINEER



8(c)



8(d)

Fig. 8(a). Schematic presentation of the type of snow conditions that could result in an avalanche. Big heavy snow blocks on an icy crust can break away even on very shallow slopes. 8(b). The construction of long, narrow snow shoes for deep snow. 8(c) Emergency signal code for downed aircrew members<sup>10</sup>. 8 (d). Emergency snow shoes for deep snow in woods.

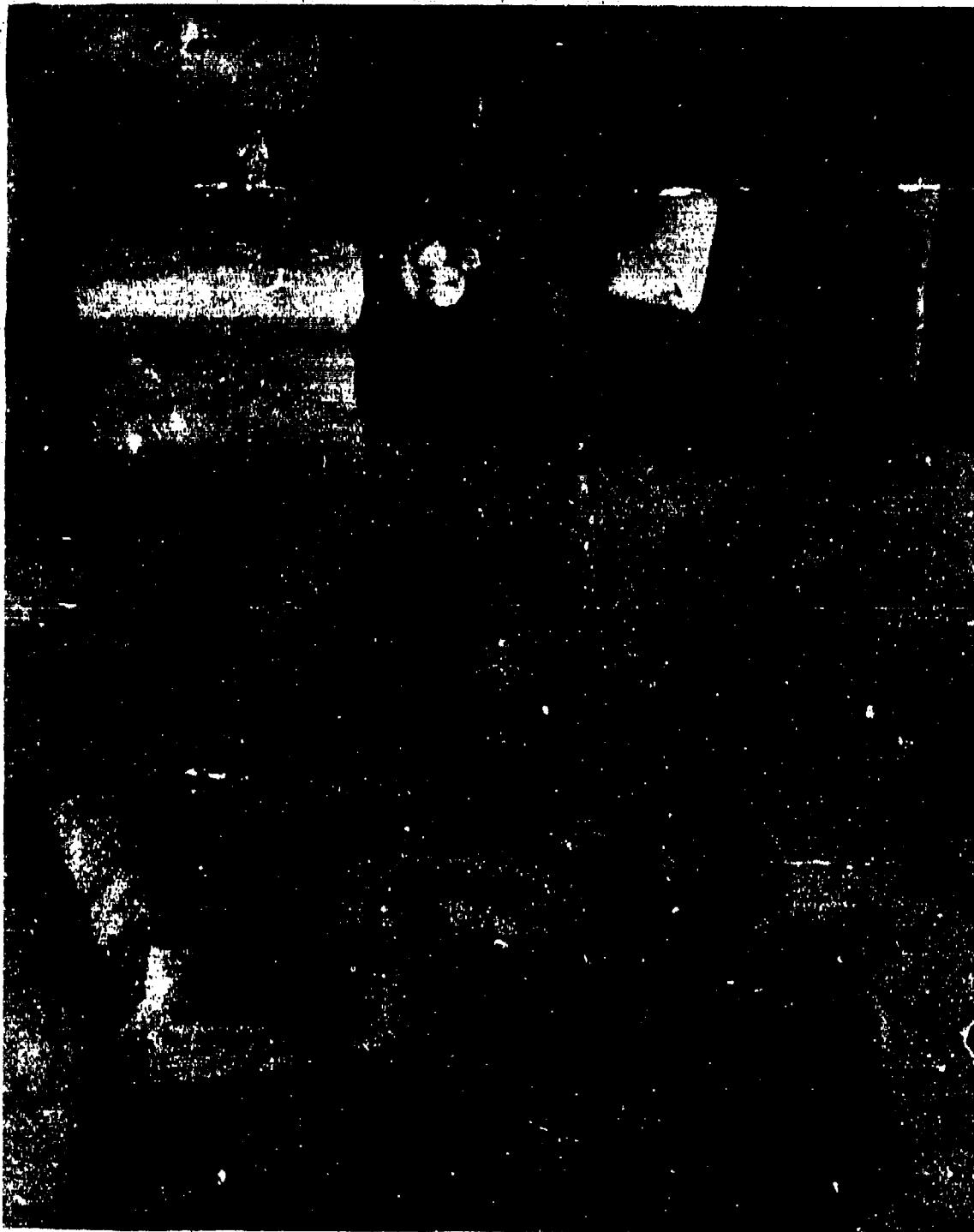


Fig. 9. Emergency Cold Weather Survival Kit. From upper right and clockwise. Small toothbrush, drinking tube, several elastic strings, sunburn ointment, safety pins, cloth bag, lipstick, vaseline, threaded needles on toilet tissue, quick tape, bandage, small tin with tape wrapped around it, tablets for headache, constipation, diarrhea and seasickness and soap.



Fig. 10 Emergency Cold Weather Survival Kit (Option 2)

## PART SEVEN

### NUTRITION

**Water.** Because water is more important than calories, water will be discussed first. Water loss occurs by means of sweating, insensible water loss, by expired air, in urine, and feces. Even a small degree of hypohydration may lead to remarkable reduction of bodily functions and later to serious symptoms such as dizziness, and syncope. Thirst is unreliable as an indicator and it is best to take in more water than thirst may indicate. Salt may be added to obtain the best electrolyte-balance.

Snow is naturally pure if not contaminated and will yield distilled water. Ice formed from snow is also pure and the water potable. When sea water is frozen and thawed several times, it will be salt-free. The remaining salt is thereby concentrated until the whole mixture freezes at lower temperature, as a "cryohydrate". When this ice is melted, the last frozen part will be thawed first, and when this water with high content of salts flows away, the pure water crystals which have higher melting points are left. If also snow is melted, one may find big fresh water ponds on sea ice.

Coarsely powdered snow or lumps of ice are preferred for melting. Loose snow requires more heat and volume and often will not sink down by itself into the kettle. Snow placed in a rubber bag may be melted by body heat as one works. Seawater should never be drunk, nor diluted with fresh water. Only where big rivers run out into the ocean will the salt content be sufficiently low. But, this water is often polluted. Do not drink urine or blood from animals. If water is very limited, the available supply should be strictly rationed during the first day. Cold water may upset the stomach and intestinal function (bacterial flora) with diarrhea and dehydration as a result. Do not drink too much. To prevent chapped lips, it is best to use a short rubber tube or to drink from a cup. Do not eat snow or ice. If fluid water is available, do not waste fuel by melting snow!

**Food.** Normally, there is no more caloric requirement in cold temperatures than under temperate conditions, assuming the microclimate temperature is within normal limits. If this microclimate temperature is lower, the caloric need may increase considerably, especially after shivering. The encumbrance of heavy and stiff clothing may add to nutritional requirements and it is typical that people tend to eat more, especially fat, when they come to the arctic. If under-nourished, people complain that they feel cold. There is a big difference between the nutrition necessary for maximal function and for that needed just for survival. Therefore, it is not possible to give fixed requirements for the amount and composition of nutrients required under all circumstances. Personal taste, storage, preparation of the food, inter-individual differences and wishes must be considered. For long survival periods, food can be identical to that eaten under normal temperature conditions. If the daily nitrogen excretion is 2 mg/BMR and with some compensation for the loss in the sweat, the food should contain a minimum of 50g protein per day. Some extra vitamin C should be taken because of the cold temperature. In earlier arctic expeditions, scurvy was frequently seen and intestinal contents from different birds and animals were eaten for their vitamin C content.

A man can certainly live without food for 8–10 days or longer, but some food is required from both a functional and psychological aspect. Since search and rescue is expected within 10–14 days, the amount of food in multipurpose survival pack may be rationed accordingly. Carbohydrates are watersparing (and antiketogenous) and are usually also easy to digest. Fat has high satiety value and experience has shown that there is special craving for fat in cold temperatures. In survival situations, one can do without protein for a short time. Tea may increase the urine output, so cocoa would be better if available. Survival food should be edible without prior preparation. On the first day in an emergency situation, one should not eat anything from the emergency pack. This statement is tempered by the amount of physical exertion that is required and weather conditions. Because heat production is increased after a meal, a specific dynamic effect, it is recommended a big meal be eaten in the sleeping bag just before going to sleep. It may provide a better sleep.

**Alcohol.** It must be stressed that alcohol should not be drunk in cold conditions. Alcohol in the blood stream dilates the skin vessels. Initially it produces a pleasant, warm feeling in the skin, especially the face and hands, but it will increase the body's heat loss. Alcohol has a hypnotic, depressing effect on the temperature regulatory center in the central nervous system. One gets careless and does not understand imminent danger or take precautions. Alcohol can abolish shivering and the metabolic reaction to cold. The risk of hypothermic narcosis and death is increased. Also, alcohol does not provide additional combustion or heat production. It displaces nutritional food supplies isocalorically from the combustion cycle. The risks are great. Many of the deaths due to hypothermia have been caused while under the influence of alcohol. It should be strongly contra-indicated. Only when it is possible to get a victim safely and quickly into a good shelter should small doses be given.

**Living off the land.** Catching fish, animals and birds will largely depend upon available equipment, although much can

be improvised. Pits can be made for trapping animals, stone or log fall traps for killing, and snares made for catching birds, and hares, and traps for fish. There are numerous methods to be tried and to be learned at survival courses.

A snare for catching hares is placed on a "hare-road" which the animal normally follows in deep snow. Also, hares often follow tracks. The loop of the snare should be 20 cm for hare. Small twigs are placed in the snow to funnel the animal to the snare (Fig. 7(a)). For ptarmigans, the loop of 15 cm is placed in an opening in a fence of twigs. This bird will often look on the other side of the fence for food. These snares can be made of any flexible metal wire, of the inner cords in the parachute shroud lines, or of nylon fishing line with the only stipulation that it runs freely. Gulls will often take a baited hook on fishing line. Plants, fungi, mushrooms require special knowledge. Some are poisonous and usually they upset the stomach, which may be very sensitive after days of hunger. Lichens also are not recommended. Many berries may be eaten but they have low nutritional value, and are also difficult to digest. Nausea, vomiting, must be avoided. If eggs are found, a simple test can be performed to determine if they are edible. Eggs rising to a standing position in water have been hatched, if they float, they are not edible. Meat of birds can be eaten raw. Meat of meat-eating animals such as seals may be infested by trichines and other parasites. These parasites are very common in polar bears and in fox. The meat of these animals should be well cooked. Meat of the plant-eating animals may be eaten raw, but it is more palatable cooked. Dead animals must never be eaten. Serious poisoning can occur after eating the liver of the polar bear (vitamin A poisoning). Inland fish are edible, although eels may be poisonous. Only a few salt water fishes are poisonous in northern areas. The abdominal contents and the blood vessels of any fish should be removed. To dry fish, cut it in thin slices and then it may be smoked. Food must be kept inaccessible from animals.

## PART EIGHT

### HYGIENE

Good hygienic practices should not be neglected. Many diseases have occurred in arctic areas due to fecal or urine contamination. Renovation, sewage, water and food hygiene must be appropriately considered. It is only natural that one becomes careless, especially in emergency situations. But, baths are important. The body can be sponge cleaned under the clothing. The feet, between the thighs, the genitals, and anal region must be kept clean. From aesthetic and psychological purposes, personal cleanliness is very important both for the person and for the group. Bad odors may be serious and have caused conflicts within groups. After bathing, some ointment such as lanoline may be applied to the skin as evaporation will be increased because of the dry air. Ointment applied several times in the day will keep the skin soft and protect against evaporation, mechanical irritation and radiation. Dry sore finger tips can be covered by tape to avoid drying out and resultant cracks. Wind and mechanical irritation from snow and ice crystals may be added problems.

It is important to keep clothes clean as dirty clothes have a lower insulative value. Special care should be taken of socks. Dirty, holey socks are poor insulators and may result in sore feet. They also accelerate fungus growth and other infections. To avoid minor problems, observe normal practices such as cutting your nails and taping sore skin before blisters develop. Put a piece of tape over blisters if they occur. It is understandable that your natural defecation pattern may be upset. With diminished food intake, defecation can be irregular and infrequent. But, there is no reason for anxiety. Constipation may sometimes be a problem and if available a mild laxative should be taken.

Long hair and beards may provide some insulation but they provide sites for frozen condensation and the likelihood of cold injury is increased. If a beard is worn, a short one is best. Shaving and washing the face should be done in the evening, because shaving removes the oils from the skin. Some people put cottonwool in the external meatus to keep the inner ear warm. This practice is not recommended as the tympanic membrane is maintained close to body temperature. Also, a block in the meatus will keep moisture on the inner side and may promote infection. Ear wax may swell and plug the canal. After a prolonged stay out in the cold, the nasal mucousa becomes dry and may be irritated upon coming into a warm room, especially in a smoky one. A nasal spray may relieve this condition. Coughing commonly occurs during the night, and it is usually best to sleep in a cooled room. Some drops of astringents may clear the nasal passageways, but frequent use of drugs may permanently damage the natural clearing by the mucous membrane. Infection with adenovirus (common cold) cannot be prevented and there is no effective treatment. Vaccination before a stay in the arctic against influenza virus is recommended for personal protection and for prevention of infection.

For prolonged cold exposures, a good sleep is a necessity. Weakness, and sleepiness has been described as the first and most important symptom which indicates hypothermia. Take a walk or make a track. In a snowcave it may be safer to sit than to lie. If there are several members in camp, one man should always be awake. Be very careful with sleeping drugs. They should only be taken when the risk of hypothermia is minimal and stimulants like coffee, caffeine, may be taken. Strong stimulants such as Benzedrine should only be used under the most serious conditions as they produce after effects of tiredness and sleepiness.

## PART NINE

### SUN AND RADIATION

The incoming radiation can be divided in, 1) ultraviolet rays (uv) with wavelengths shorter than 400 nm. 2) visible rays-wavelengths 400-750 nm, and 3) infrared with wavelengths longer than 750 nm.

The uv rays will "burn" the skin. Even with a complete cloud overcast, there may be considerable uv-radiation. A great part of incoming radiation is also reflected from snow and may double the exposure.

**Sunburn.** After a symptomfree latency of one to four hours, ultraviolet radiation will induce an actinic inflammation with redness, heat, swelling, burning pain, often fever, later vesicles, and as a final result pigmentation. Infection, dryness, mechanical irritation may promote symptoms. The resultant effect can be very severe and completely incapacitate a man. Remember: There are no alarm symptoms and the initial symptoms at low temperature may be masked by reduced sensitivity. Timely precautions must be taken. Wind and infrared radiation will increase the symptoms. There is considerable interindividual difference in sensitivity - one man may suffer while another will not have any difficulty. Light complected persons are most susceptible and must take special precautions.

Many simple ointment bases absorb uv. rays because of impurities (cyclic aromatic compounds). Yellow vaseline affords good protection and is better than the white, refined type, but vaseline gets too soft at moderate temperatures and will soil clothing. Most of the ointments used are complex emulsions with oil in a water phase. The oil phase contains usually a chemical compound which has high specific absorption of the most damaging rays (350-380 nm). The content of water should be low. When a white emulsion type of ointment is rubbed on the skin, the white color will often disappear. A popular conception is that the ointment is rubbed into the skin, but the water is simply evaporating. The oil phase will remain on the surface with specific absorbing effect and will relieve the burning pain. A very thin layer is sufficient for protection, but, if the exposure is strong it should be renewed several times a day on projecting parts. The lips require special attention to avoid chapping.

Other precautions include casting a shadow over the face. Fabric or paper can hang down protecting the lips and nose (Fig. 7(b)). Natural skin fat should not be washed off. Strong alkalic soap makes the skin more hygroscopic, and vulnerable and should not be used.

There is no effective treatment for sunburn after the damage has occurred. Powder, sterile dry bandage, anesthesia in ointment, cortisone and butazone can be tried. Cold air and wet wrappings may be used if blisters develop.

**Chapped lips.** Lips are very sensitive to uv radiation. After some latency, they may become painful swell and crack. This condition is very difficult to correct. Some people are very sensitive and all moisture, sweat, water or snow may result in chapped lips. As previous discussed, a rubber tube should be used for drinking. Don't lick the lips. Do not eat snow or suck ice. In an emergency, snow can be eaten but make small compressed balls and do not touch the lips. Ordinary herpes can often develop in addition to the "radiation and drying"-lip-lesion with cracks, swelling, infection. The herpes simplex virus or a preivirus is widespread and seems to be activated by wind and sun. The only protection is by ointment or lipstick.

**Snowblindness.** Strong visible light is dazzling and can be very annoying. Visual acuity will be reduced and headache and fatigue may follow. Ultra-violet rays are absorbed superficially in the conjunctiva and cornea of the eye and can "burn". "Snowblindness" results in a redness, feeling of sand, pain, running eyes, swelling, eye muscle cramps, and hazy vision. Very rarely does real blindness occur. There is a symptom free interval after the exposure of two to three hours. The symptoms are stronger indoors than outdoors. Commonly, a person does not react as long as he is out in the cold, but becomes symptomatic upon coming indoors. There is no adaption and it is interesting that the Eskimos and Lapps have been able to adjust without special protection.

Ordinary window glass, refractive glasses and most plastic will absorb the greater part of the uv radiation from the sun and prevent any tissue damage. Quartz is the only glass with high uv. transmission. In strong light glasses should absorb visible light and should be dark. A neutral grey or slightly green color is preferred. The glass should be sufficiently thick to absorb the ultraviolet. Within the visible range, the absorption should be around 60-80 per cent. If the exposure to this radiation is severe and of long duration, there should also be side shades. If corrective glasses are worn, it may be practical to have a loose "shade" which can be put on in front instead of sunglasses. Blowing snow may come in between the two glasses, and it is best to have the necessary absorption in the corrective glasses. Glycerin and surfactant detergents may reduce fogging of the lenses. The framework material used for the

glasses should not crack in extreme cold and there should be no metal part in contact with the skin. The metal parts can be covered with paper, fabric, tape, or a thread. Polarized lenses are good for snow glare. In an emergency, eye protection can be improvised with a handkerchief, cloth, or paper, with a horizontal slot. Some sooting around the eye may reduce the glare.

There is little one can do after the exposure. Dark goggles, dark room, cold wet compresses over the eyes provide some relief. Instillation or leaflets with cocaine or similar drugs placed in the eyes will take away the pain, but the healing is retarded. Therefore, cocaine should be avoided and morphine taken orally must be preferred.

*Eye cold damage.* Wind, blowing snow and ice crystals can result in pain and impaired vision. Tearing is also very annoying. Serious pain had been reported in skaters, skiers, and pilots in open aircrafts who have been exposed to cold. Microscopically small lesions of the fine cells which constitute the fine coating on the cornea have been seen under these circumstances. These lesions are found mainly in the lower quadrant where the eyelid does not cover the cornea. The damaged area is related to reduced blinking with evaporation and disruption of the tear film. Contact lenses are of some help. It is interesting that the cornea is not damaged more by the cold as it has no blood-vessels. If a person is instilled with cocaine and does not blink, the risk of cold damage is increased.

There has been some discussion that myopia could develop after a severe exposure to both light and cold, but this is doubtful. If the pupil is contracted under these conditions, it is a result of the light reflex and does not lead to convergence or accomodation.

"White out". "White out" usually occurs during the wintertime when the ground is snow covered and when there is no visual reference points such as stones, shadows. In this situation, it is difficult to evaluate the horizontal and vertical planes and distance. Everything looks white. One may feel dizzy and tense and tries to avoid falling. The condition can be very tiring. Ordinary sunglasses should be worn. In difficult terrain, it helps to throw something ahead, such as a skipole anchored to the arm with a string. It will break the monotony for the eyes, and prevent falling down a precipice or releasing an avalanche.

## PART TEN

### PSYCHOLOGY, PERSONNEL SELECTION, AND PHYSICAL FITNESS

*Psychological profile for arctic duty.* Many psychological problems are associated with cold climates. Experience from expeditions show that under dire emergencies, it is ultimately the mental fortitude, the "will" to live which may be the decisive factor. In a group, selection of a good leader is essential. It is difficult to assess those personal attributes amenable to a stay in the arctic beforehand, but psychologists maintain the importance of a prior interview. A person who has been to the Arctic before and wants to go back will probably handle emergencies better than a novice, but there are many factors that are difficult to predict. Arctic experience and physical condition are of primary importance. Knowledge and training with the equipment is secondary. All personnel should undergo a thorough medical examination. Overweight persons will often have a lower physical standard, but will have a slight insulative advantage. In terms of basic thermoregulation, all human races are identical. Previous trauma (mechanical, vibrational, thermal), deformities, skin conditions and skin diseases, fungus, varicose veins, nasal stenosis and high sensitivity to sun and radiation all must be considered before assigning a person to the Arctic.

*Physical fitness.* In coping with an environmental stress, the level of physical fitness is important. Many body functions benefit as a result of a rigorous program of physical fitness. There is an increase in muscular strength and better neuromuscular coordination, increased heart stroke volume and a higher fibr concentration and rapid cardiovascular recovery after exercise. Circulation is enhanced and good constriction of peripheral blood vessels occur during cold exposure which conserves body heat. Higher glycogen stores and ability to tolerate high concentration of lactic acid, an indication of effective anaerobic pathways in combustion increases. Well trained people endure trauma infection and accidents with less damage than the untrained, with a shorter recovery period. Physical training, even in warm climates, will allow a more rapid adaption to cold.

*Survival training.* All personnel who run the risk or who have to stay in the "cold land mass" should take an indoctrination or survival course. It is important. The hardships and danger associated with cold temperature must be recognized and how to cope in a survival situation. People must learn how to utilize available equipment effectively. Suitable topics for a cold weather survival course have already been discussed in this paper and should include the following :

Basic physiology of temperature regulation and cold exposure, loss of insulation associated with sweating, insensible water loss, and dehydration. Sudden incapacitation because of alcoholic beverages, carbon monoxide and drugs poisoning. Solar radiation and snowblindness, protection from sunburn, importance of clothing, shelters, campsites, snowcaves, how to dry clothing, frostbite treatment, how to improvise emergency equipment such as snow shoes and to use the parachute as a sleeping bag. Participants should stay outdoors in the cold with survival equipment for one or two nights in a snow cave or tent. Ski training and the use of emergency signals should be taught. By being exposed to such a course, the participant will learn what to do and to do it immediately before losing hand dexterity or becoming hypothermic. Needless anxiety, panic and purposeless hyperactivity can thus be avoided.

## PART ELEVEN

### ORIENTATION AND TRAVEL

**Orientation.** A compass is a necessity. The compass should have phosphorous on the needle, at the north, on the housing, and on the arrow showing direction. It must be absolutely clear which end of the compass needle points towards north. If you are completely confused and disoriented, you will feel safer if you have written on the compass: "red end points north". Everything which may prevent nervousness and panic is important. How to determine the north-south axis from the position of the sun and a watch must be known. It is more accurate as one approaches the north pole. But, with a midnight sun, there is a possibility for 180° error. The sun is south when it is highest and north when it is lowest. The shade from a stick on a horizontal surface will show this axis. Some stars and constellations should be known and followed. People know that stars move 360° in 24 hours as does the sun and moon, but few are aware that "starry" is in the east and that a star moves (360°/24) = 15 degrees westwards per hour, on the southern sky. The northern polar star is so high in the skies at high latitudes that it gives inaccurate information. The moon is full in the south at 2400. Each additional hour signifies 15° westwards. The increasing half-moon (convexity rightwards) is in the south at 1800 hours and the moon moves eastwards 15 degrees from day to day.

Usually the vegetation is richest on the south side of any hill, but may be equally lush on the north side with the sun shining 24 hours in the summer time. There are many subtle clues that depend on powers of observation.

Because of the freezing action of water, melting occurs on the surface of ice and the water often runs off with repeated freezing and thawing. Thus stones, pieces of wood in ice will move upwards and after some time they will lie on top of the ice. Here they may float around on the Arctic Ocean for years and do not indicate anything about the distance from land. Birds may tell more. One has to be cautious as one visually may under-estimate distance because of the extremely clear air.

**Travel.** There must be an overriding reason for leaving the vicinity of a crashed aircraft. Physical training, experience and the equipment must be very good. It is usually not recommended. Snowshoes may be needed and the dog-sled can be used as a sledge. Ice covered rivers often afford an excellent route. If rivers are followed, walk on the inside of the curves. On the outside the water is deeper and the ice thinner. It may be treacherous when the ice is covered by insulating snow. Bare ice is usually safest. Leave some markers to show your passage and information for possible search groups. Stay away from icebergs.

If one is forced to wade a river, one should take off socks and other clothing to keep them dry. Walk barefooted or with only boots on. Get support from a stick or a line from shore. Walk upstream. Cold cramps may occur quickly, especially if a person is fatigued. As soon as practicable, dry the skin and inside of the boots with some cloth.

**Immersion in ice water.** If one falls in water, the heat loss is precipitous and tactile discrimination is rapidly reduced. The raft must be boarded, if possible, within one minute. Heart irregularities, respiratory difficulties may result in drowning or sudden death even if one is a strong swimmer. In cold water the total heat loss from the extremities is relatively smaller than from the body. The heavier the clothing the more heat is conserved. Swimming will increase heat production, but the heat loss is greater. As a rule, remain motionless in the water, or swim slowly.

**Storms.** If threatening clouds indicate an approaching storm, take a rest, eat, dress, and make suitable plans. Always keep a compass and a map ready and note a course and expected time for the different legs. A group must stay close together. You should have only emergency equipment in the pockets of a pack such as scarf, mittens, storm goggles, compass, some food and extra clothing. Shelter may be the only alternative and digging a snow cave should be started immediately. Do not try to force your way against a storm. It will be difficult to walk against and to see or hear. You could easily stumble and gusts of wind may throw you to the ground. Any damage to yourself or to your equipment may very quickly lead to disaster. Do not sit down!

**Avalanche.** Falling snow may accumulate in large drifts on the lee side of any hill. From a mountain or a steep slope the loose snow may avalanche down with great velocity. When the sun has warmed the surface of the snow, subsequent cold will form an ice layer mainly on south and southwest slope of a hill. Snow which falls on top, may lie for some time. But this new snow will recrystallize and loose, powdered snow will form over the ice layer. Dangerous avalanche with big snowblocks may be released even from innocent looking slopes. Most of the big and dangerous avalanches actually come from slopes of only 20–30°. If one has to traverse dangerous slopes, there must

be considerable distance between each man and a long line should hang from the first man. If he is covered by an avalanche, the line may "float", while the man usually will sink down and be buried. If you are caught in an avalanche, keep your arms in front of the head for protection and to create the best possible air space. People have survived even after being buried many hours, and resuscitation must be tried even when it seems hopeless.

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